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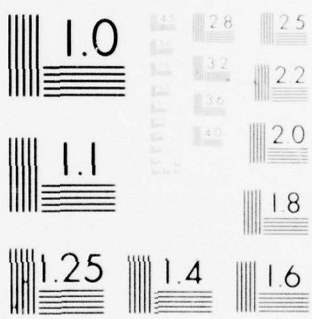

MICROCOPY RESOLUTION TEST CHART

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TECHNICAL REPORT H-77-10

POSITIONING TECHNIQUES AND EQUIPMENT FOR U. S. ARMY CORPS OF ENGINEERS HYDROGRAPHIC SURVEYS

by

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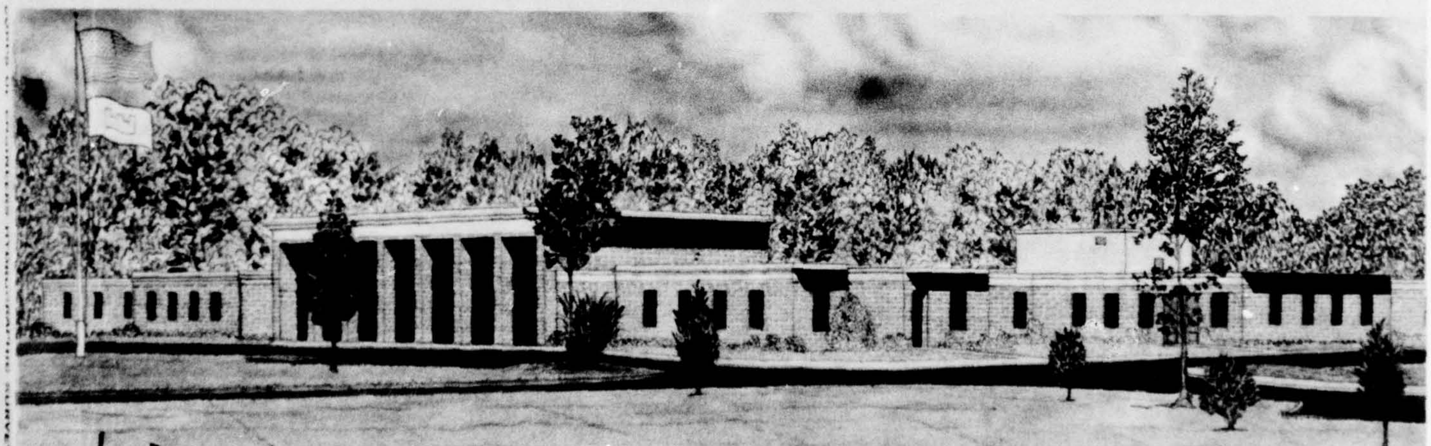
May 1977

Final Report

Approved For Public Release; Distribution Unlimited



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This report describes techniques and equipment that can be used by U. S. Army Corps of Engineers personnel in the 38 Districts to perform hydrographic surveys. These techniques should improve each District's operating efficiency by reducing the time lag between data collection and final report or completed chart. The report uses simple explanations and nonmathematical descriptions of the subjects covered and should be readable by all levels of survey branch personnel. Names and addresses of manufacturers' representatives are included in
(Continued)

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20. ABSTRACT (Continued).

cont.

Appendix A to aid the reader in obtaining up-to-date technical information. A list of key Corps personnel engaged in hydrographic surveying is included in Appendix D to facilitate information interchange.

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PREFACE

The hydrographic survey positioning equipment (electronic, acoustic, and optical) described herein was known to be available at the time of publication. The information regarding commercial equipment was obtained through a continuous monitoring of the appropriate literature and through telephone conversations with and personal visits to private firms involved in the development and sale of hydrographic surveying equipment. Knowledge of techniques in use within the U. S. Army Corps of Engineers (CE) was obtained in conversations with Survey Branch personnel from CE Districts in various parts of the country.

This study was sponsored by the Office, Chief of Engineers (OCE), U. S. Army. Funds were provided the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) from the OCE Improvements of Operation and Maintenance Techniques Program. The study was conducted under the general supervision of Messrs. H. B. Simmons, Chief, Hydraulics Laboratory, and E. B. Pickett, Chief, Hydraulic Analysis Branch (HAD), with assistance provided by the Instrumentation Services Division (ISD) under the direction of Mr. F. P. Hanes, Chief, ISD. The report was prepared by Messrs. G. C. Downing, Chief, Dynamics Branch, ISD, and E. D. Hart, Chief, Prototype Branch, HAD.

Directors of the WES during the study and the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) AND METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
U. S. Customary to Metric (SI)		
inches	25.4	millimetres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. nautical)	1.852	kilometres
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
knots (international)	0.5144444	metres per second
degrees (angle)	0.01745329	radians
Metric (SI) to U. S. Customary		
centimetres	0.03280839	feet
metres	3.280839	feet
kilometres	0.6213711	miles (U. S. statute)
kilograms	2.204622	pounds (mass)
Celsius degrees or Kelvins	9/5	Fahrenheit degrees*

* To obtain Fahrenheit (F) degrees from Celsius (C) readings, use the following formula: $F = 9/5(C) + 32$. To obtain Fahrenheit readings from Kelvins (K), use: $F = 9/5(K - 273.15) + 32$.

POSITIONING TECHNIQUES AND EQUIPMENT FOR U. S. ARMY CORPS OF ENGINEERS HYDROGRAPHIC SURVEYS

PART I: INTRODUCTION

General

1. The U. S. Army Corps of Engineers is engaged in a wide variety of hydrographic survey operations most of which are conducted within the continental United States, but some occur in scattered and remote areas of the world.

2. This report is addressed primarily toward the continental United States type survey positioning operations and equipment that entail work in inland waterways, such as estuaries, harbors, canals, rivers, and reservoirs. Limiting the scope of this report to inland waterways considerably reduces the area of information coverage that would otherwise be required, since equipment and techniques adapted to this type work are far less numerous in extent than for offshore work. Furthermore, such an approach will make this report more useful to Corps District personnel who are expected to be the primary readers.

Purpose

3. This report is intended to be a source of general information for personnel engaged in inland waterway hydrographic surveying. Commercially available positioning equipment is listed in some detail to aid the reader in determining what is available and to aid in accomplishing District work. Manual and optical techniques are described briefly to aid comparison with electronic methods and to generate ideas for special purpose uses of these techniques.

Corps Hydrographic Survey Mission

4. The operations of the 38 Districts of the Corps are very diverse

in scope and nature of work. Each Corps District is unique in the combination of factors that act as constraints and determine work load demands. In the hydrographic surveying field, this diversity of requirements has precluded the standardization of techniques and equipment throughout the Corps. It has, in some cases, inhibited the adoption of new technology because no one system could satisfy all of the operational demands of even a relatively localized area. Instead of looking for an all-purpose system, the reader can perhaps examine his survey needs on the basis of work to be done and then arrive at a cost effective (but not perfect) program for modernization of District methods.

Corps Geographic Considerations

5. As an aid in analyzing a problem area, it is frequently helpful to categorize relevant factors. If an attempt is made to classify District survey operations, it immediately becomes apparent that there are so many combinations of terrain, operational procedures, project constraints, etc., that no one method is adequate as a classification base. Since an all encompassing classification appears impossible, consider first a specific classification base--waterway type. Figure 1 is an idealized pictorial that compresses the main waterway types into a small area. A degree of literary license was taken in relating the waterway types with men who have pioneered in applying automated survey methods to each category of District work.

6. Using waterway types as a primary classification element, it is logical to further classify significant survey factors according to surrounding terrain types as a second dimension and nonphysical factors as a third dimension. The result is a three-dimensional cube shown as Figure 2 that arranges these factors in a form readily visualized as a checklist when considering new equipment and techniques. While there are exceptions, most of our District operations are conducted in waterways that can be categorized within the bounds of the factors summarized in this figure. Each combination of constraints visualized from Figure 2 may call for a different combination of equipment components in order

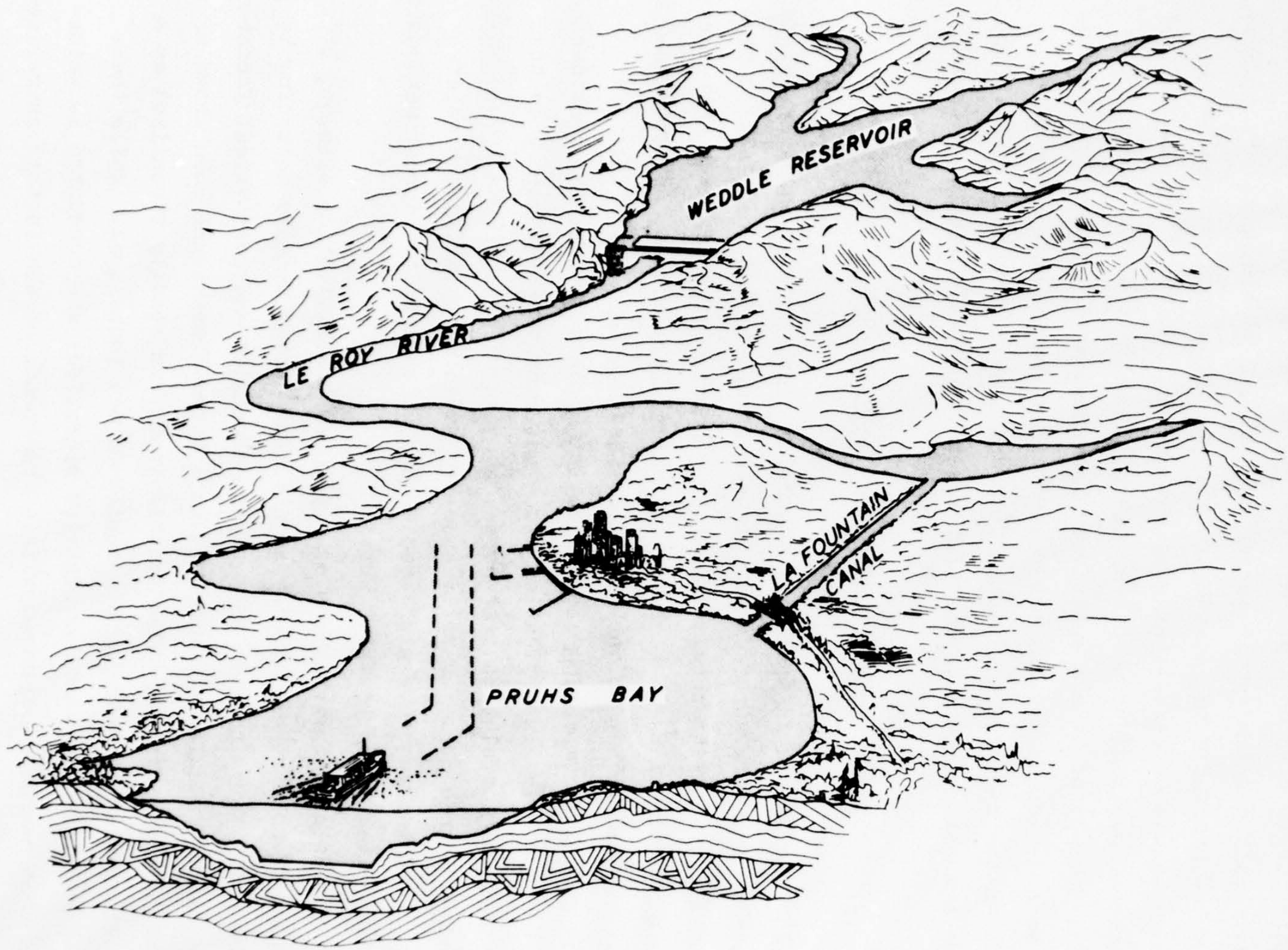


Figure 1. Inland waterway types

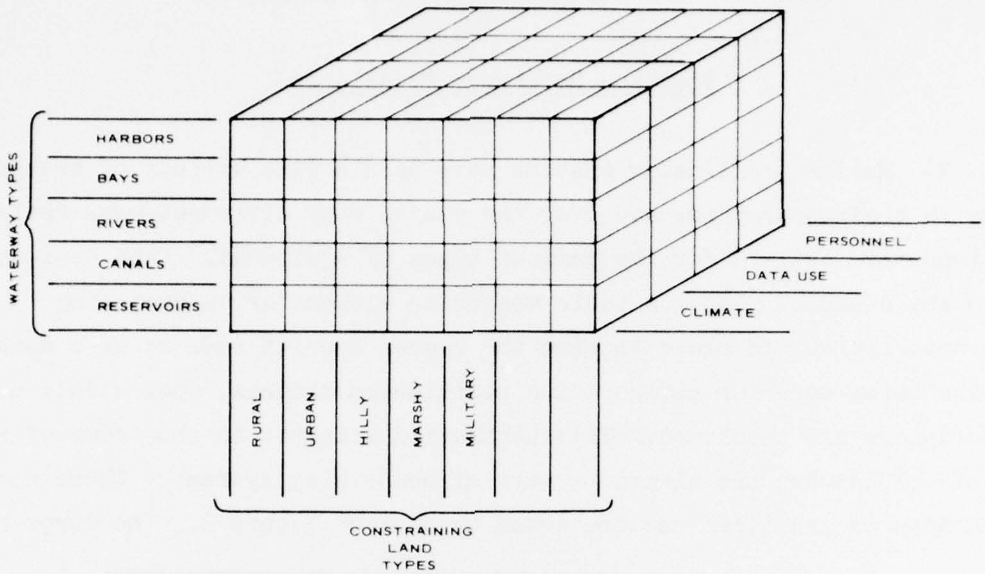


Figure 2. Survey classification features

to arrive at an optimum survey system for a given job. Since most District operations entail the use of equipment on a wide variety of projects, the selection of an optimum system becomes very subjective. As can be seen from Figure 2, the many compartments of the cube show that the number of possible combinations far exceeds the total number of Corps Districts. Therefore, this explains the many different approaches used by different offices, all with good reasons.

PART II: POSITIONING SYSTEM CHARACTERISTICS

Position Reference Techniques

7. Marine positioning systems have used a wide variety of techniques in their operation, and over the years, many different user designations have evolved for the various types of equipment. Each designation may describe either a basic measuring element or an operating characteristic. In order to give the reader a quick summary of a number of the terms used for categorizing positioning systems, some widely used descriptors are tabulated. This tabulation attempts to show some of the relations between the alternate ways of describing systems. Those combinations in practical use are noted by an X on Figure 3. The Corps has

		MEASUREMENT MEDIUM OR COUPLING								
		NONLINE-OF-SIGHT			LINE-OF-SIGHT					
		VERY LOW FREQUENCY (VLF) 10.0 – 13.0 KHz	LOW FREQUENCY (LF) 100.0 KHz	HIGH FREQUENCY (HF) 1.6 – 3.3 MHz	ULTRA HIGH FREQUENCY (UHF) 0.3 – 3.0 GHz	MICROWAVE 3.0 – 10.0 GHz	OPTICAL	ACOUSTIC	MECHANICAL	MAGNETIC
POSITION REFERENCE TECHNIQUE	ACTIVE RESPONDER			X	X	X		X		
	PASSIVE REFLECTOR					X	X			
	DOPPLER					X		X		
	INERTIAL								X	
	SATELLITE					X				
	MANUAL						X		X	
	BEACONS	X	X	X	X	X	X	X		
	ASTRONOMICAL						X			X

Figure 3. Categories of positioning system techniques

probably, at one time or another, used all of the basic techniques in accomplishing its missions. However, a major shift in technology usage

within the Corps has occurred within the past few years as many Districts have been changing from manual to electronic techniques.

8. Within the categories listed in Figure 3, there is a wide variety of commercial equipment available to a potential user. Since specific equipment types will be discussed in other parts of the report, a listing is given in the following paragraphs of some of the well-known equipment types according to category. This listing should be useful to the reader in understanding references made to each type later in the text. Lawhead[1] in a recent publication describes alternate methods of classifying positioning systems with particular emphasis on military systems.

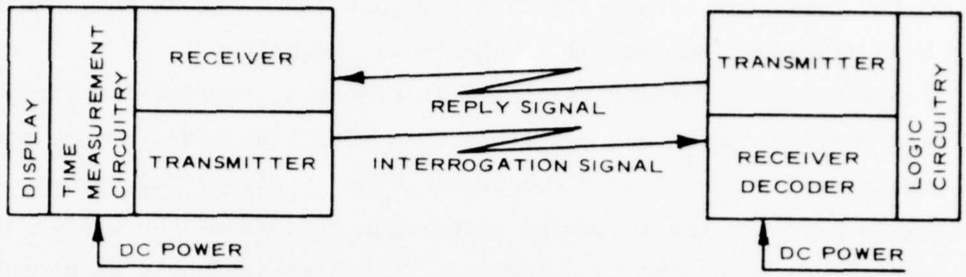
Active responder systems

9. Active responder equipment includes those types of distance-measuring equipment (DME) that have one unit to transmit an interrogation pulse and a second unit to receive the interrogation pulse and reply with an answering pulse, which can be decoded to derive range (and, when necessary, the channel also). A simplified sketch of an active responder DME is shown in Figure 4. The coupling between the interrogator and responder may be radio waves, optical beams, or acoustic waves.

10. Because of the large variety of available equipment, active responder equipment is the category most widely used by the Corps at present. Commercial equipment in this category includes: (a) VHF-Raydist (R-R) and Hi-Fix (R-R); (b) UHF-Maxiran (R-R) and Slydis; (c) microwave-Autotape, Tellurometer, Trisponder, Mini-Ranger, Miniran, and Artemis; and (d) acoustic-Digi Trak.

Passive reflector systems

11. Passive reflector positioning systems also use the DME to transmit signals but differ in that the response signal is the reflected energy from the shore (Figure 5) instead of a response transmission as with active responder systems. Marine radar is an example of this type equipment in which the passive reflectors are the natural shoreline features or man-made structures, such as buildings and ships. Other types of passive reflector DME use specially shaped reflectors to send back a high percentage of the incident energy. Other examples of this type



INTERROGATOR	RESPONDER
(1) TRANSMITS CODED INTERROGATE SIGNAL	
	(2) RECEIVES SIGNAL
	(3) RECOGNIZES CODE
	(4) TRANSMITS REPLY SIGNAL WITH KNOWN TIME DELAY
(5) RECEIVES REPLY SIGNAL	
(6) MEASURES TIME INTERVAL FOR ROUND TRIP AT SIGNALS	
(7) DISPLAYS TIME INTERVAL DIRECTLY AS DISTANCE	

Figure 4. Active responder DME

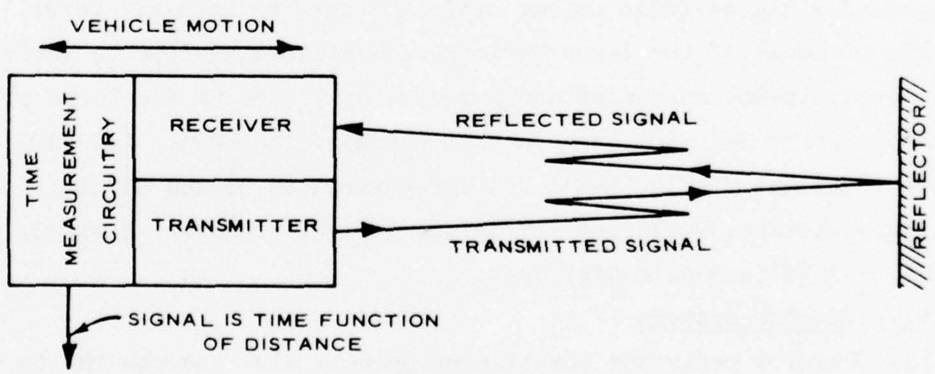


Figure 5. Principle of passive reflector DME

equipment using optical components are the infrared (IR) DME, such as the Hewlett-Packard distance meter and the Cubitape. Dynamic optical positioning equipment using passive reflectors (Corner Cube) is manufactured by Sanders and GTE/Sylvania. Dynamic microwave positioning equipment using passive reflectors is made by Associated Controls and Communications, Inc., and NanoFast. Microwave positioning equipment

using passive reflectors but requiring manual adjustment is made by Alpine Geophysical Associates, Inc.

Doppler navigator systems

12. Doppler navigators transmit signals and detect reflected energy similar to passive reflector systems, but the detection circuitry, in this case, is based on the measurement of frequency change of the signal due to the velocity of the moving vehicle (Figure 6). Therefore, doppler

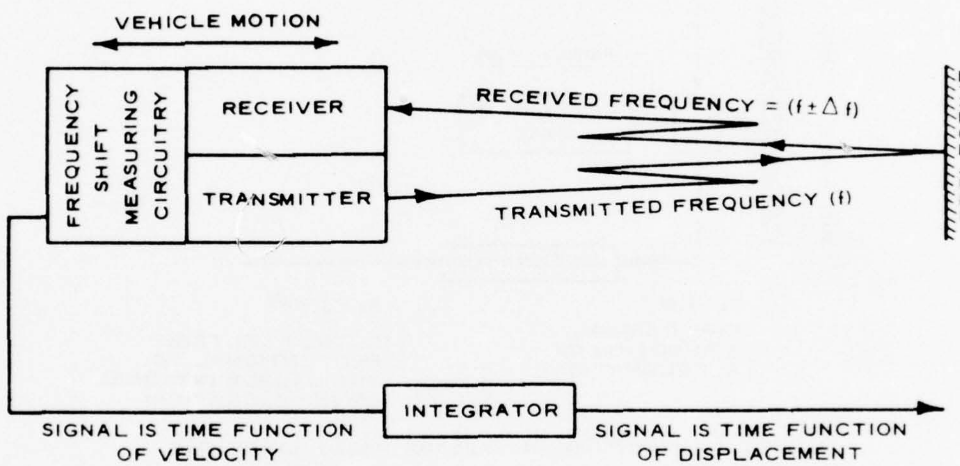


Figure 6. Doppler navigator principle of operation

navigators are basically velocity-measuring systems instead of distance-measuring systems. Since displacement can be mathematically derived from velocity, by integration with respect to time, it is possible to compute vehicle position based on a known starting position and the measured velocity vector. Doppler navigators will work without need for knowledge of the location of the reflective surface. Thus, they offer great freedom of operation since there is no need to stay within range of shore responders or reflectors.

13. Accuracy with doppler navigators is inversely proportional to time from the starting point, since any integral computation involves the summation of the small errors inherent in any measurement. Doppler navigators are used on submarines, aircraft, and ships as the primary navigation system or as supplements to other types of positioning systems.

14. Manufacturers of doppler navigators include: (a) acoustic-Edo Western, Raytheon, Sperry, and Ametek/Straza; and (b) microwave-Singer.

Inertial navigator systems

15. Inertial navigators make use of the basic physical law that acceleration causes a predictable force to be exerted on the mass involved in the motion (Figure 7). Displacement can be mathematically

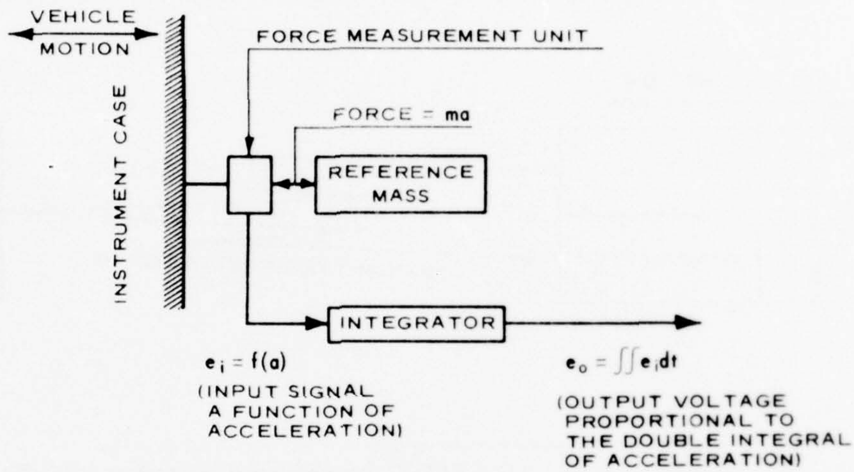


Figure 7. Inertial navigator basic principle

computed from an acceleration/time measurement; therefore, it is theoretically possible to compute movement from a starting reference point. The computation of displacement from acceleration involves a double integral compared with the single integral required for the computation of displacement from velocity.

16. Dramatic positioning performance has been shown to be possible with inertial navigation equipment on missiles and aircraft. These systems require no external reference signals for operation since all information is derived from the self-contained inertial sensing elements. Precision accelerometers are used to measure three orthogonal linear acceleration vectors, and gyros are used to determine the angular motion of the vehicle. Continuous electronic integration of the sensor signals provides velocity and position information for control and data purposes.

17. As with any integration computation, the errors are cumulative. Velocity error is a direct linear function of sensor accuracy and time.

Position error is a combined function of velocity sensor error, heading sensor error, integration time, and computation errors. Due to the inherent cumulative error in all integration computation, the positioning accuracy will be inversely proportional to time squared. Inertial navigators are for this reason limited to short-time duration use, such as for aircraft or missiles.

Satellite positioning systems

18. Satellite positioning systems make use of man-made satellites as a position reference. Since the satellite orbits can be accurately predicted, the position of a ship can be determined by measuring doppler shift at several spaced times (t_1, t_2, and t_3) as the satellite passes within measurement range (Figure 8). Due to the high speed of the satellites, it is necessary to make all measures dynamically and to use a

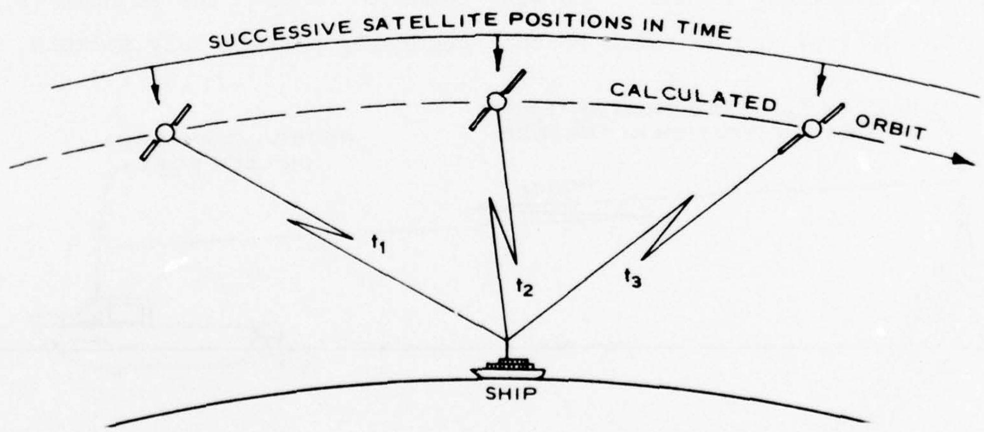


Figure 8. Satellite positioning system

computer to process the data. Satellite positioning is currently still in its infancy, but some practical use is already being made with this technique. The Navy has sponsored the development of the satellite equipment now in orbit, and at the present stage of development, "fixes" can be obtained about once an hour at the latitudes involving the continental United States. With the present Navy satellite system, this technique must be used in conjunction with a complementary system, such as an acoustic doppler navigator, when dynamic positioning is needed. Static fixes are useful for some land survey needs. A greatly improved

satellite positioning system called NAVSTAR is under development for use in the next decade.

Manual position reference systems

19. The Corps has for many years used manual methods for positioning its marine vessels. Manual procedures have involved transits or sextants for optical reference sighting and wires or cables for mechanical reference. Manual methods are described in more detail in paragraphs 27 and 28.

Beacons

20. Beacons have been used for many years as marine aids to navigation. Lighthouses are probably the best-known example of this type of position reference. Beacon positioning systems radiate optical, radio frequency, or acoustic energy from known locations, and the reference signal is available to all users with means to receive the signals (Figure 9). Optical and acoustic beacons generally provide only azimuth

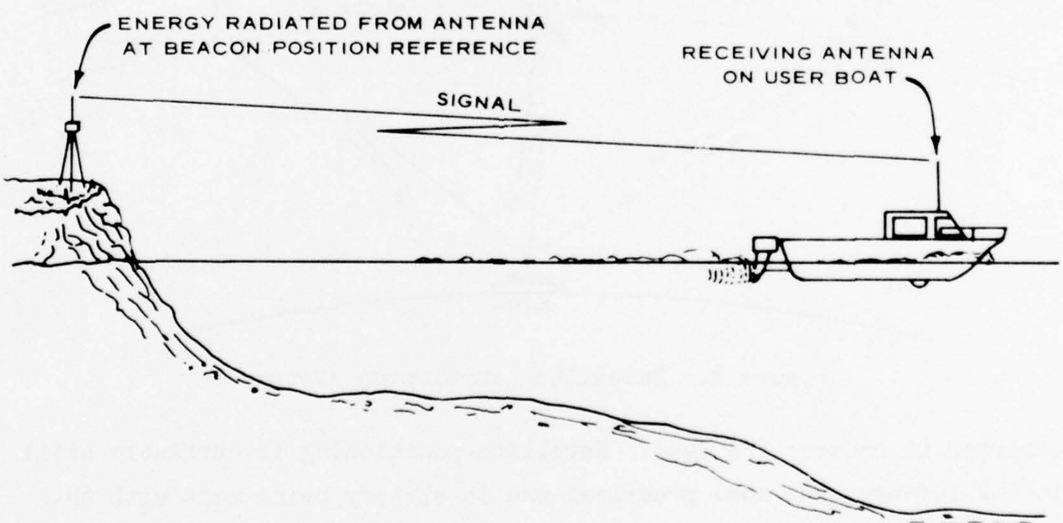


Figure 9. Beacon position reference principle

information to the user. Radio beacons are widely used azimuth references, but some, such as Omega, Loran-C and Hyperbolic Raydist, are used to provide distance information to the user based on the wavelength of the signal.

Astronomical positioning

21. Navigating by the stars is older than history and is still in use. Its inclusion in this report is only for the purpose of completeness of the tabulation. For inland waterways, astronomical techniques do not offer sufficient accuracy to be used.

Nonline-of-Sight and Line-of-Sight Systems

22. The most widely used positioning systems in use by the Corps are generally electronic DME grouped into the categories of nonline-of-sight or line-of-sight. Commercial examples are discussed in Parts III and IV. The nonline-of-sight active responder systems use one or more frequencies in the band from 1.6 to 3.3 MHz. Most line-of-sight active responder systems use operating frequencies selected in bands ranging from 2.8 to 10 GHz.

23. Equipment operating in microwave bands (2.8 GHz and higher) is limited to line-of-sight operation due to the high signal attenuation of intervening objects, such as trees, hills, and buildings. Microwave DME can operate through fog, rain, and haze that would preclude visual sighting. Thus, it is actually better in operating capability than the term line-of-sight implies. Compared with optical positioning techniques, microwave DME enables crews to operate in weather conditions precluded by earlier methods. Compared with nonline-of-sight equipment, microwave equipment offers higher accuracy and repeatability.

24. Equipment operating at frequencies from 1.6 to 3.3 MHz has much lower signal attenuation than microwave equipment, and this characteristic permits positioning work to proceed in areas that would block line-of-sight signals. Trees, hills, buildings, etc., are significant but not prohibitive obstacles for nonline-of-sight DME. With judicious use, nonline-of-sight equipment permits operating freedom unattainable by any other means.

25. The foregoing comments are intended to draw the general bounds of modern positioning system capabilities. Subsequent paragraphs will give in abbreviated form the pertinent features of individual systems available commercially. As these systems are studied, remember that

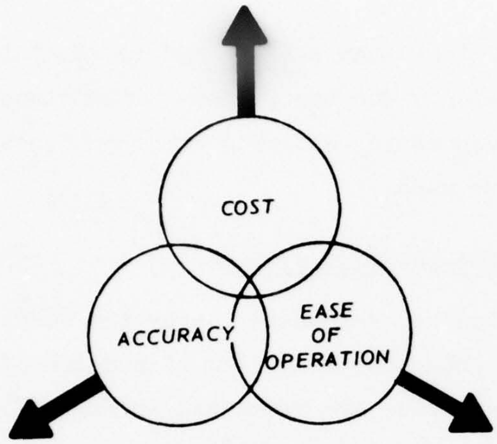


Figure 10. Major compromise factors in system selection

no one system is best. Instead, each must be considered as a compromise solution to an operating need. Figure 10 emphasizes the fact that each equipment analysis must weigh the application needs versus the system features. All selections must reach a reasonable compromise in cost, accuracy, and ease of operation.

Preelectronic Positioning Techniques

26. In the beginning and prior to the availability of electronic positioning systems, optical and mechanical boat positioning techniques were used by the Corps offices. These techniques are still in use in some areas and may still be the optimum choice in operating applications where capital investment limitations are more critical than the labor involved in data collection and processing. A brief summary of these techniques will be given in the following paragraphs to aid the reader in comparing all methods now available.

Manual optical tracking

27. A widely used optical boat positioning technique requires the establishment of two transit stations at known shore locations to permit both operators to have line-of-sight viewing of a selected operating area. By taking simultaneous sighting on the survey boat, a position "fix" can be determined and correlated with a depth reading. This

technique is illustrated in simplified form in Figure 11. The position of the survey boat is calculated on the basis of a trigonometric solution where the baseline and two angles (θ_1 and θ_2) are known. For most

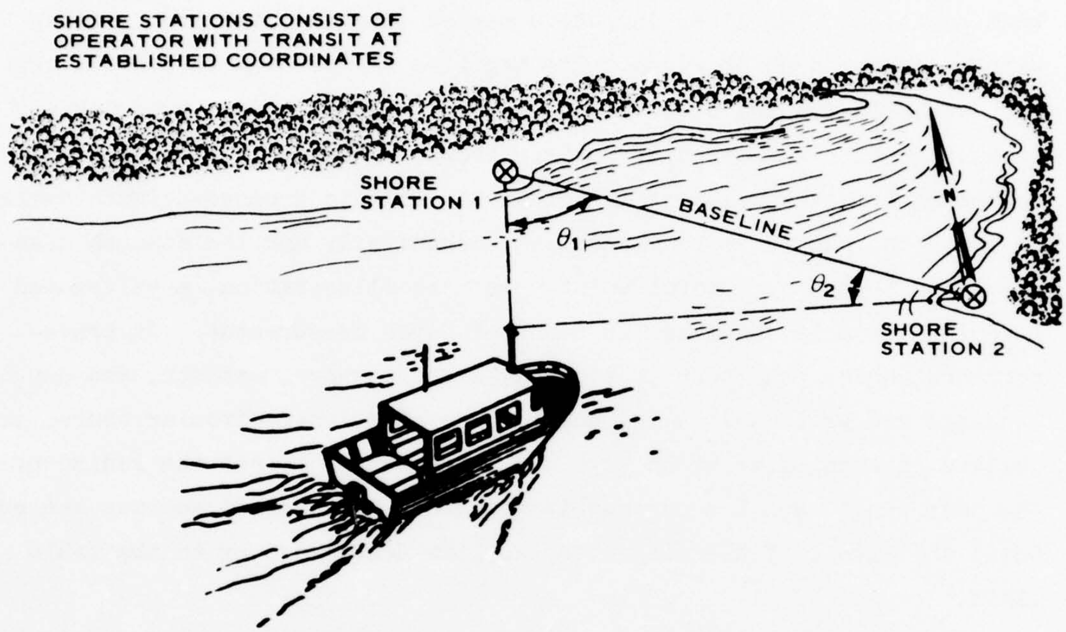


Figure 11. Optical tracking of survey boat

purposes, the transit stations must be at coordinates established by land surveys, which are tied into an accepted grid. Various methods of making fixes have been devised by different field groups. The predetermined angles method uses one transit to guide the boat and the second transit to determine when the boat passes points calculated for predetermined angles. A number of other methods have been devised to fit particular operating conditions, e.g., the use of sextant measurements from the survey boat of established shore monuments. The availability and use of two-way radios in recent years permits more versatility in operating procedures than was previously possible.

28. The automatic optical trackers available now could be direct replacements for manual tracking using this basic technique. The high cost of such equipment and the availability of more cost effective techniques have eliminated Corps interest in this direction.

Tag-line system

29. Wire lines (generally called tag lines by the boat crews) have been used for many years as a means of determining or maintaining survey boat position. Tag lines include a marked (tagged) steel cable along with a control drum or winch. The tag line may be used to control the boat path (Figure 12) or to measure the linear distance a boat has moved cross channel. The circular pattern shown in Figure 12 is well adapted to the equipment complement illustrated. This is a range-azimuth system in which the range can be controlled mechanically and the azimuth measured from the shore control point. In this illustration, a calibrated lead-line drum is shown as the means of depth measurement. At predetermined angles, the boat is stopped, and the range, azimuth, and depth readings are written in a log book. After the inner circular course is checked, the tag-line winch pays out enough cable to set the radius of the next range, and the process is repeated. Additional courses are run until the extent of the suspected shoal is determined or to the cable limit.

30. Figure 13 illustrates a tag-line system for running straight-line courses in a cross-channel mode, as well as the use of a transit for guiding the boat in the prescribed course across the channel. The transit operator guides the boat operator across the waterway so that a cross section of the channel is obtained. Figure 14 shows a tag line coupled with an acoustic depth sounder instead of a lead line being used for measuring depth along the selected path. Readings from the tag line and depth sounder may be written in the log book for appropriate distance intervals. In some instances, the tag-line winch will have a switch installed that is electrically connected to the depth recorder and that creates distance marks automatically on the depth chart, or it can be used as the position input for the small-boat data logger shown in Figure 101.

31. Tag lines are limited to short distances compared with most other methods. River currents are difficult to contend with, and the operation is time-consuming. In heavily trafficked waterways, the passing boats can be extremely dangerous as well as disruptive to operations.

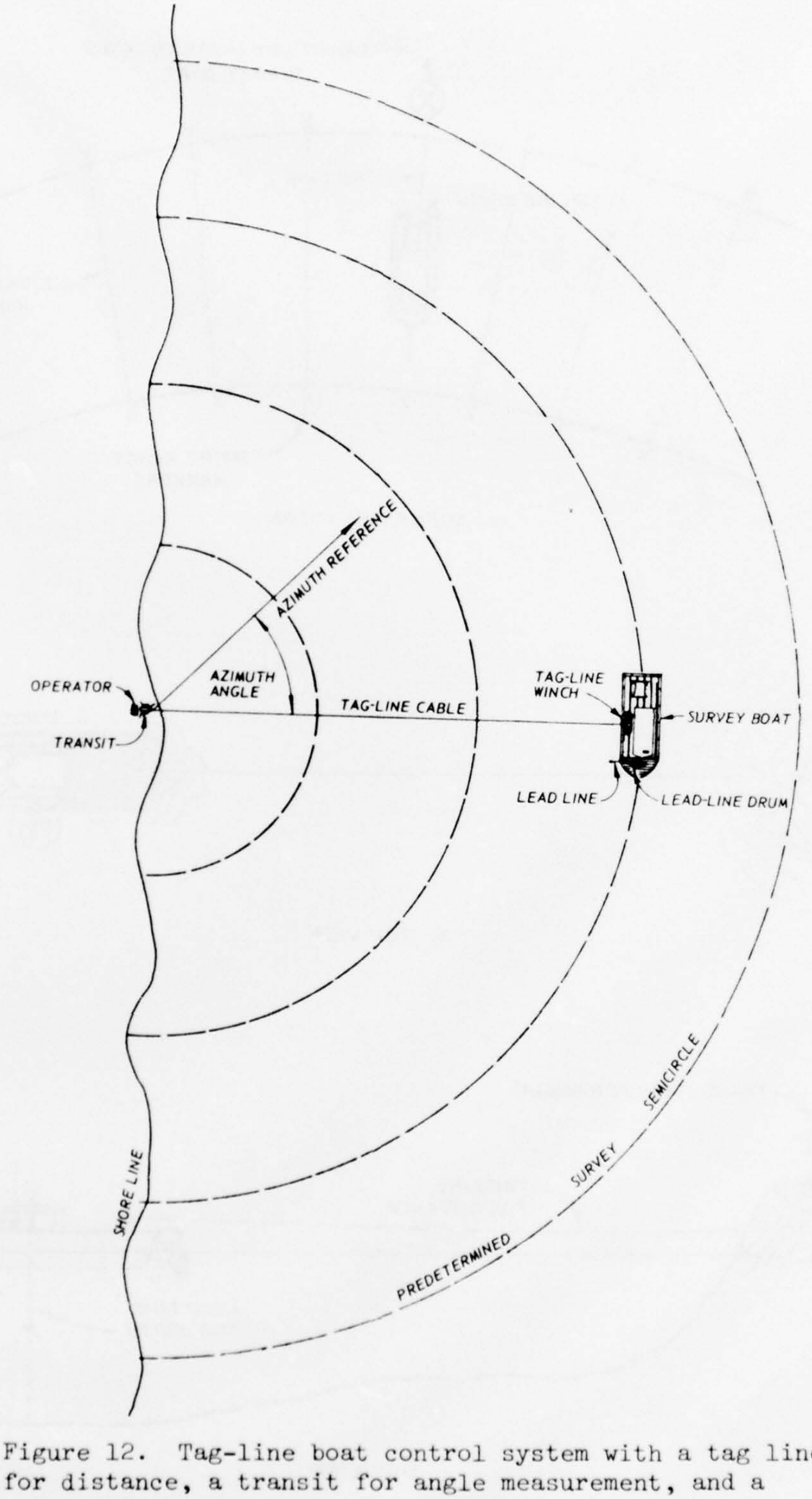


Figure 12. Tag-line boat control system with a tag line for distance, a transit for angle measurement, and a lead line for depth

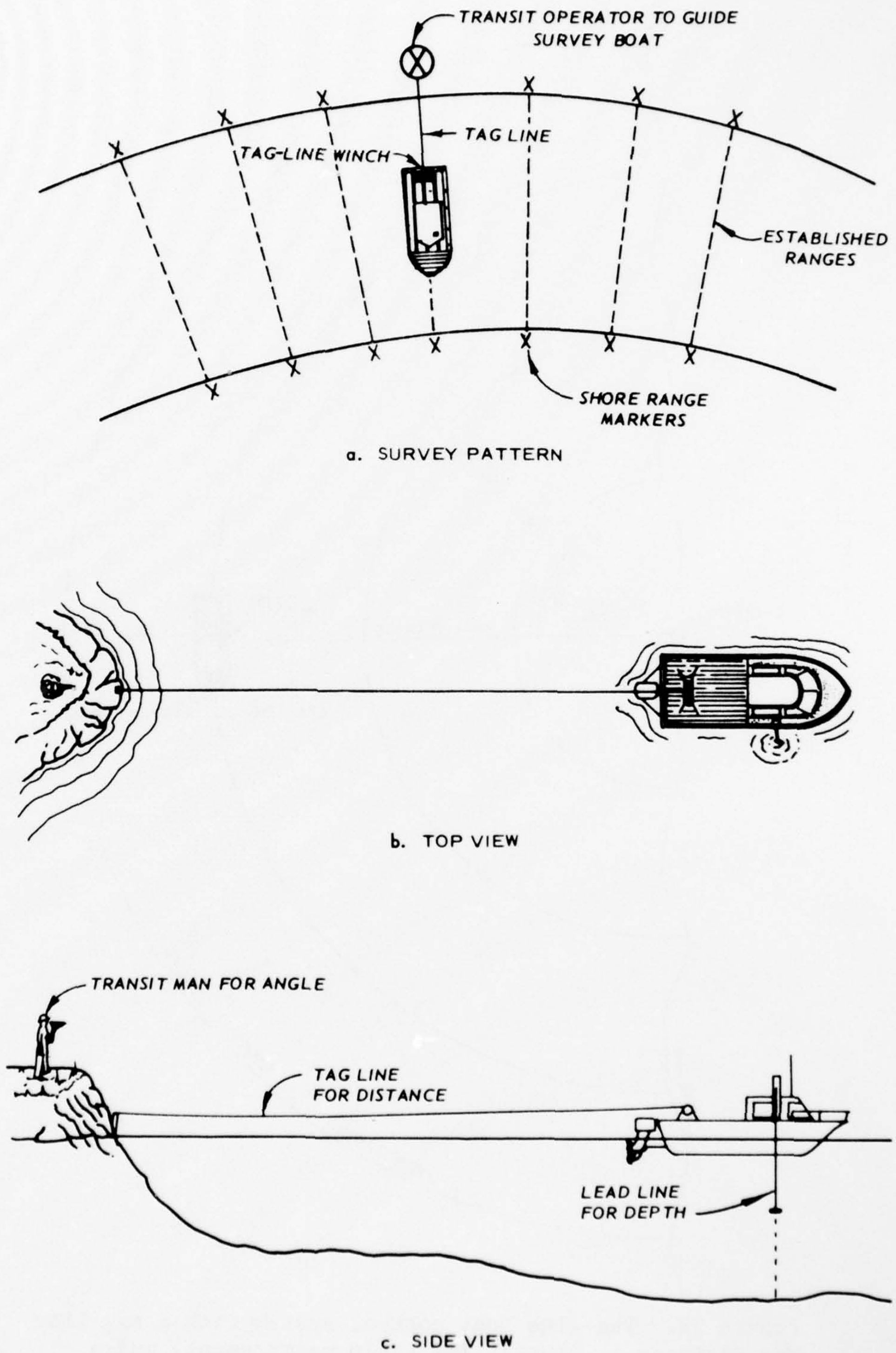


Figure 13. Tag-line system for cross-channel surveys

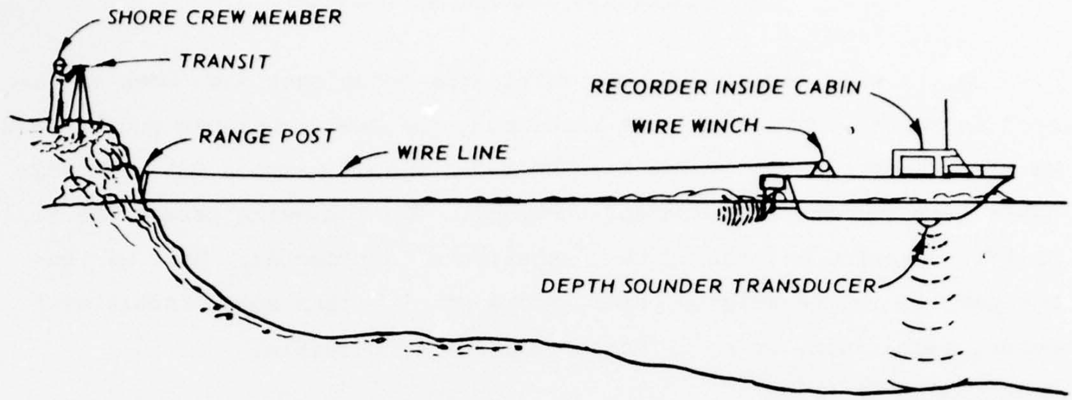


Figure 14. Tag-line system with acoustic depth sounder

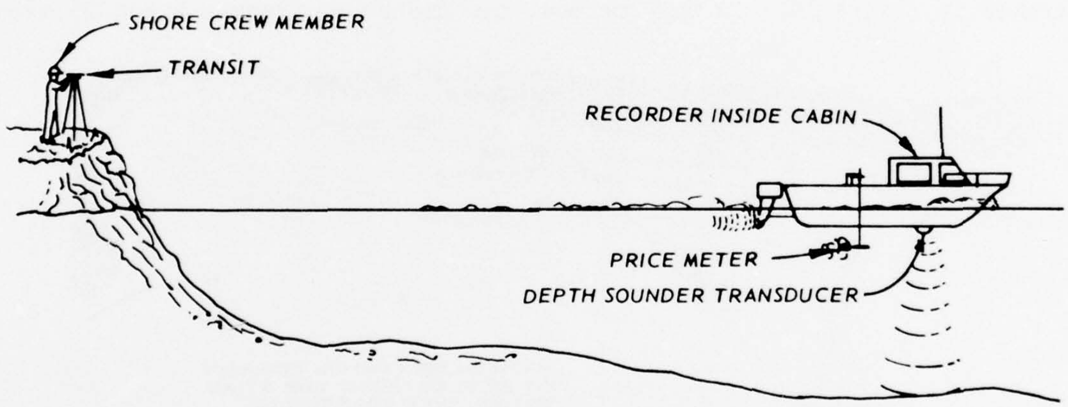


Figure 15. Survey system using current meter for distance measurement

32. In Figure 15, the use of a price current meter as an alternate to a tag line is described. The current meter gives pulses approximately proportional to distance when the river currents are low. This approach is not as limited in distance as wire lines are and does not present a waterway traffic hazard but does present a cumulative error problem.

33. Range poles may also be used in lieu of a sextant for path guidance. This reduces the number of personnel required in a survey party. However, the problems with this method include the requirement of continuous undergrowth clearing and right-of-way permits.

Electronic Positioning Techniques

34. A wide variety of new positioning techniques have been developed in recent years. In some instances, the new techniques can be used as almost direct substitutes for the older manual methods but with valuable improvements in speed and accuracy. The following paragraphs will briefly describe several of the "substitute" approaches. Some of the new positioning techniques permit modes of operation not possible with manual techniques, so no direct comparison is possible.

Range-range tracking

35. The closest analogy to the two-transit optical technique, using electronic positioning equipment is the range-range technique illustrated in Figure 16. In this method, two distances (ranges 1 and 2) are

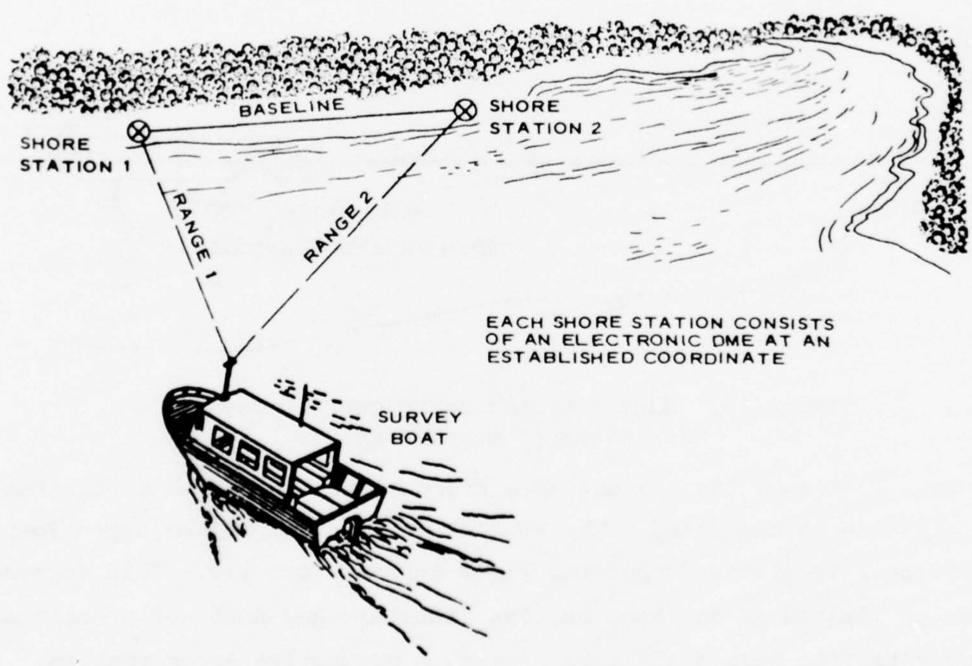


Figure 16. Range-range tracking of survey boat

measured electronically from the survey boat to two known shore stations. The position of the survey boat is calculated on the basis of a trigonometric solution where three sides are known--a reference leg plus two measured ranges. As with the optical method, the shore station locations

must be tied into an accepted grid in order to establish boat position for plotting purposes. The electronic positioning system not only provides measurements to permit calculation of boat position at all times but also makes it possible to obtain automatic boat guidance.

36. The range-range positioning technique is the most commonly used mode for electronic positioning systems. As a result, the majority of commercial systems are manufactured as two-range units.

37. Range-range positioning systems with underwater acoustic signal transmission are available commercially. These systems are effective in offshore and deep ocean work but cannot function reliably in shallow and variable depth water. Since nearly all Corps survey work is on inshore or inland waterways, this technique is not considered applicable to this study and is not described further. A list of manufacturers is, however, given in the supplement to the 1973 Corps Hydrographic Survey Conference Proceedings.[2]

Range-azimuth tracking

38. The range-azimuth approach can be used in several ways, with electronic equipment substituting for mechanical equipment. A modern range-azimuth system can be implemented by using a single-range electronic DME coupled with a manual or automatic optical or microwave tracker. This technique is illustrated in Figure 17. One combination

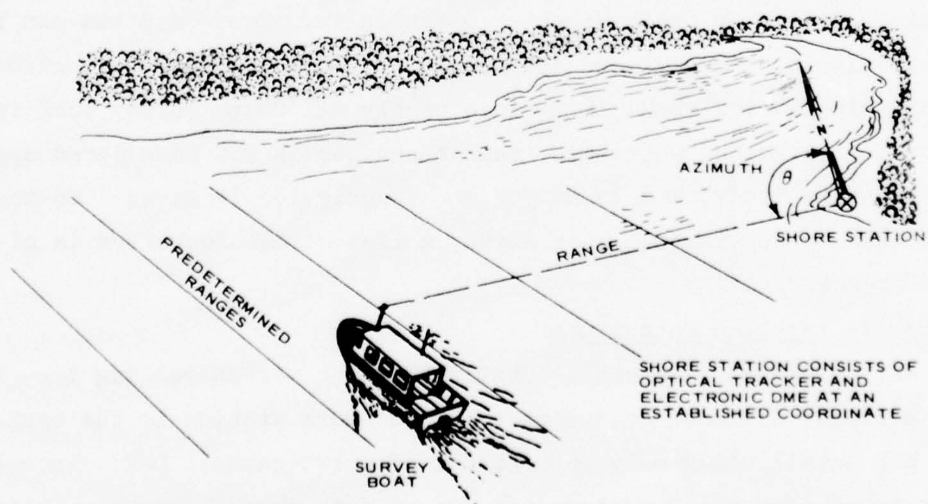


Figure 17. Range-azimuth tracking of survey boat

currently in use is to have an operator with a transit at the shore station determine the boat azimuth (θ). The azimuth "cuts" are relayed to the survey boat by means of radio, and the distance measurement or range is read on the DME on the boat. These measurements along with the depth sounder chart provide the data necessary for the survey. The range-azimuth tracking systems have certain advantages over their range-range counterpart. These include: (a) ability to operate over larger areas because line-of-sight clearance is required from one station only; (b) geometry better for maintaining approximately the same accuracy within the shore station field of view; and (c) fewer shore stations needed for the survey.

39. A commercial system (Odom) using a manually directed optical tracker coupled with a single-range electronic DME is described in Part IV. Automatic optical trackers are currently so costly that they are considered only for military or special purpose jobs and are not discussed in this report.

40. A commercially available range-azimuth system (Artemis) with automatic tracking of range and azimuth is also described in Part IV. This system uses a microwave band for its operating frequency and is not limited by fog, haze, etc., as an optical azimuth tracker would be.

41. Range-azimuth positioning systems with underwater acoustic signal transmission are available commercially. These systems can be effectively used in offshore and deep ocean work but cannot function reliably in shallow channels. Since nearly all Corps survey work is on inshore or inland waterways, this technique is not considered applicable to this study, and so no further description is given. In the event that an application does exist, a list of manufacturers is given in Reference 2.

Electronic tag-line substitute

42. A direct electronic substitute for a mechanical tag line is to make a single distance measurement from a shore station to the boat. This may entail using only one channel of a two-channel DME, since the majority of commercial systems are two or more channel units. Shore survey requirements remain the same as for the mechanical tag line;

however, the electronic tag line has no significant distance limit, entanglement problems, river current problems, or boat speed limitations, and interfaces readily into automatic data acquisition equipment. The commercial units suggested for this method are presented in Part IV.

Electronic current meter substitute

43. A direct electronic substitute for the current meter method is to use a single-range acoustic doppler speed log. This method has no significant distance limit, entanglement problems, water current problems, boat speed limitations, or equipment required on shore, and readily interfaces with automatic data acquisition equipment. A commercial unit suggested for this method is described in Part IV. As a word of caution, however, acoustic doppler speed-measuring equipment will not work in waterways with a layer of sediment moving along the surface of the consolidated bottom. This limitation occurs because the equipment receives the acoustic signal reflected from the moving sediment and the circuits react the same as they would to a similar signal reflecting from the consolidated bottom. Doppler systems have a cumulative error like the Price current meter technique but much lower in magnitude.

Accuracy Considerations

Positioning accuracy

44. Accuracy is a very complex and possibly ambiguous term when applied to hydrographic surveying, for the proper meaning depends on such a large number of parameters. For example, the accuracy with which the dynamic position of a boat can be determined is dependent not only upon the accuracy of the DME but also upon the following:

a. Speed of the boat.

b. Position of the DME antenna on the boat.

c. Pitch, roll, and yaw effects on the relative position of the DME antenna and the sensor.

d. Difference in the data transfer rate of the DME and the depth digitizer.

e. Geometry of the positioning system.

f. Accuracy with which the shore responder position is known.

g. Time for the DME to take a measurement.

h. Recording error rate.

i. Atmospheric conditions which affect velocity of propagation.

j. Smoothing rate of the DME.

DME accuracy

45. The accuracy of the DME is considered first, for this is basic to a positioning system. Other factors can have a vital impact on positioning accuracy, but in general they are things to avoid and not things to compensate for the limits set by DME accuracy. All electronic DME works on the basic premise that the transit time of electromagnetic energy from source to receiver will be constant for most practical purposes, whether radio frequency or microwave. Thus, by measuring the transit time of a radio frequency or microwave signal between two points, it is possible to determine the distance between them (Figure 18). The

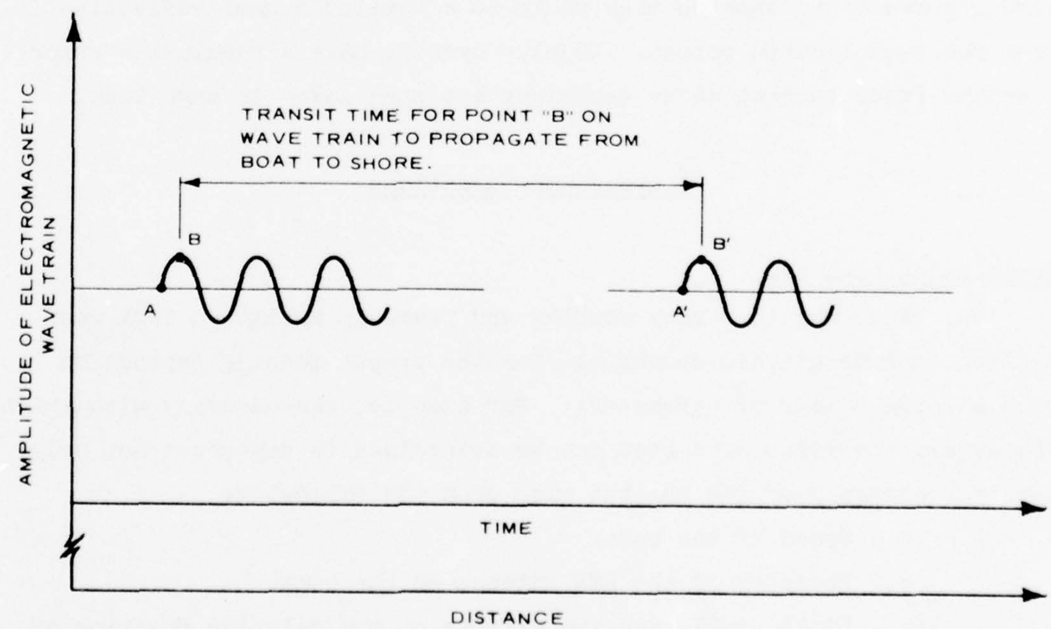


Figure 18. Measurement of transit time of electromagnetic energy

velocity of propagation of electromagnetic energy is an exact constant only through a vacuum. When electromagnetic energy travels through an

air medium, which occurs in all hydrographic survey applications, the velocity will be slightly slower than in a vacuum. Commercial electronic DME is calibrated at standardized air conditions for temperature, pressure, and humidity. In field use, these parameters may vary widely and cause very minor changes in calibration. Where the highest accuracy is needed, the transmission path can be monitored for these parameters, and the appropriate corrections can be computed. Regular checks of DME accuracy can be made by comparing the boat position at known locations with the positioning equipment readings. Some types require periodic adjustment to compensate for minor drift in the equipment.

46. Electronic DME can be divided into two general categories defined by the manner in which transit time is determined. One category uses pulse techniques whereby: (a) a pulse is transmitted from a master unit; (b) the pulse is received by a shore unit; (c) the shore unit sends a response pulse; and (d) the master unit measures the roundtrip time. Pulse techniques are used in these DME: Trisponder, Mini-Ranger, Miniran, and Maxiran. The other category of the DME determines transit time by measuring the phase of a received signal referenced to a transmitted signal. Phase detection is employed in the Raydist, Hi-Fix, Cubic, and Tellurometer systems.

Speed effects

47. Several speed effects contribute to positioning accuracy and should be considered in evaluating or defining system accuracy. First, and most important, is the time required to make a measurement. For microwave phase comparison systems, it is necessary for the circuits to cycle through a comparison sequence requiring approximately 1 sec to complete. The distance the boat travels during this cycle time can be very significant in a high-speed survey boat. Depending on the relative point in the measurement cycles for both depth and the two ranges, the measurements acquired will have a time offset that is effectively a distance offset between depth and position. The speed offset effect can be largely corrected by computer processing of the data.

48. Pulse-type microwave DME completes its measurement cycle time in a shorter period than microwave phase-comparison systems, so the

speed effect errors are less. For example, one manufacturer of pulse-type DME uses a design with approximately 25 msec needed for a 10-sum reading and 115 msec for a 100-sum reading. The time skew for this system is thus only one-fifth the time skew of a system that requires 1 sec to take a measurement.

49. The processing of the depth measurements may also introduce time skew effects that in turn cause speed dependent errors. If smoothing of the depth measurements is performed to eliminate spurious readings, this may introduce time skew in the depth relative to position on the recorded data. Careful digital filtering can smooth the data without introducing a lag in the depth data relative to the position data.

50. The operating technique of the data acquisition system can introduce speed effects also. If the data acquisition system samples depth and the two ranges simultaneously, no speed effects will be introduced. If the data acquisition system samples depth and the two ranges in sequence, a time skew offset will occur that will cause an effective positioning error, which will be dependent on boat speed and data acquisition system speed.

Antenna position on boat

51. The position of the DME antenna on the boat can have a significant impact on the positioning accuracy of the system regardless of the basic range accuracy. For example, if the DME antenna is mounted on the center line of the boat while the depth transducer is offset from the center line, due to mounting constraints, then the uncertainty of the depth measurement position is twice the port/starboard offset unless complex corrections are included in data processing. Figure 19 illustrates the port/starboard mounting offset to be avoided, if possible. In a similar way, the fore/aft mounting of the DME antenna (Figure 20) relative to the depth transducer should be considered, for this offset distance is likewise an added error unless corrected in data processing. Even when the static position of the DME antenna is directly above the depth transducer, some dynamic considerations must be taken into account. Figures 21 and 22 show the effect of pitch and roll of a survey boat on the relative position of the DME antenna with respect to the depth

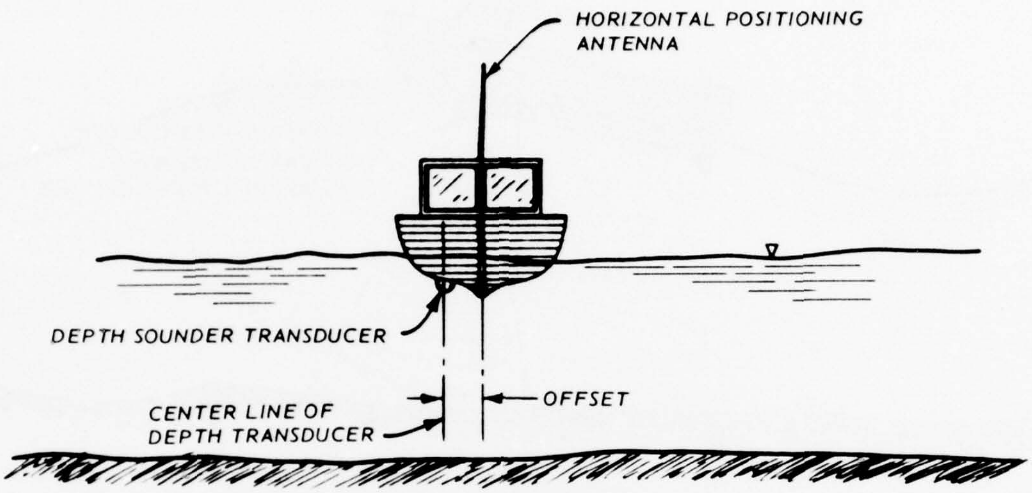


Figure 19. Antenna/transducer port/starboard offset due to mounting

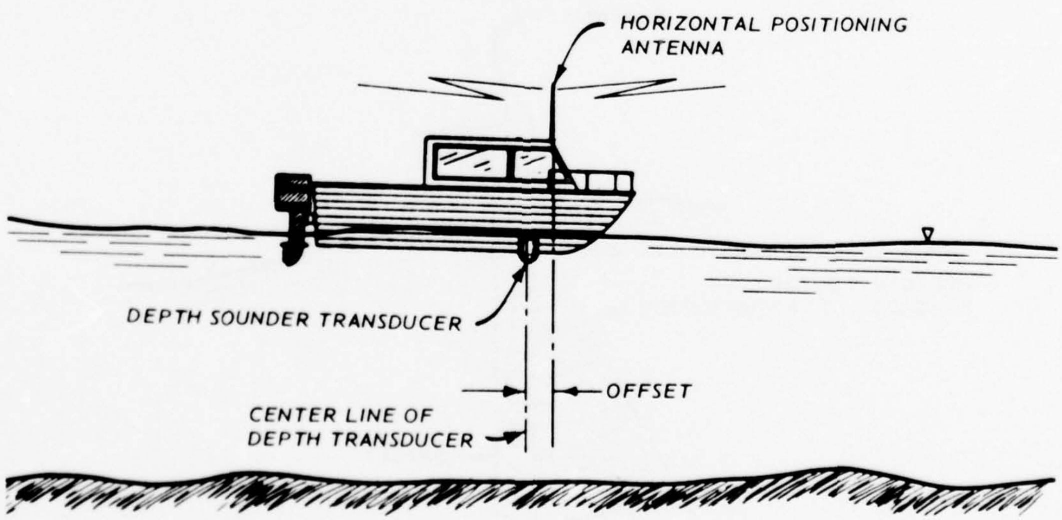


Figure 20. Antenna/transducer fore/aft offset due to mounting

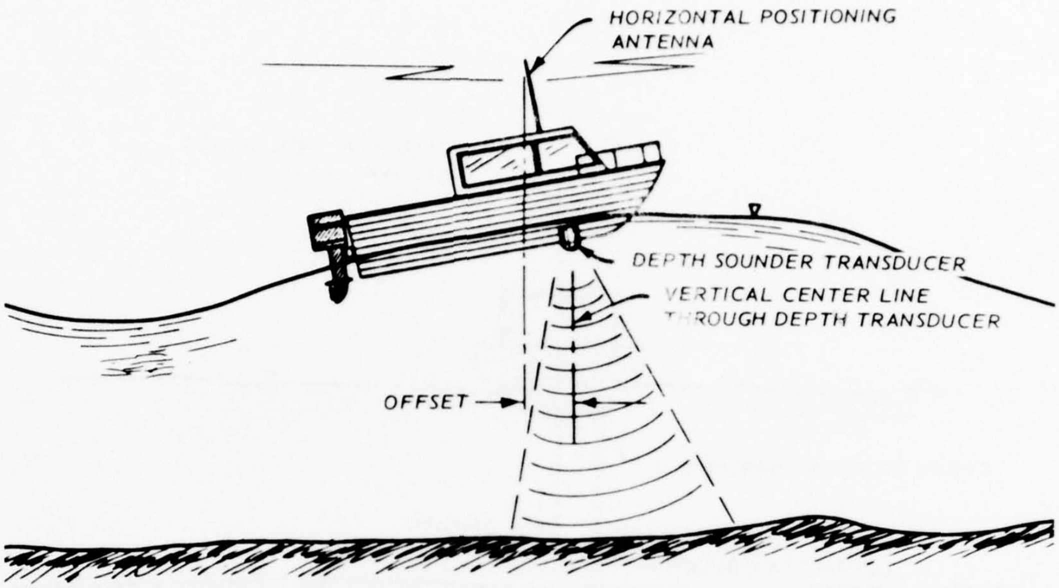


Figure 21. Antenna/transducer fore/aft offset due to pitch

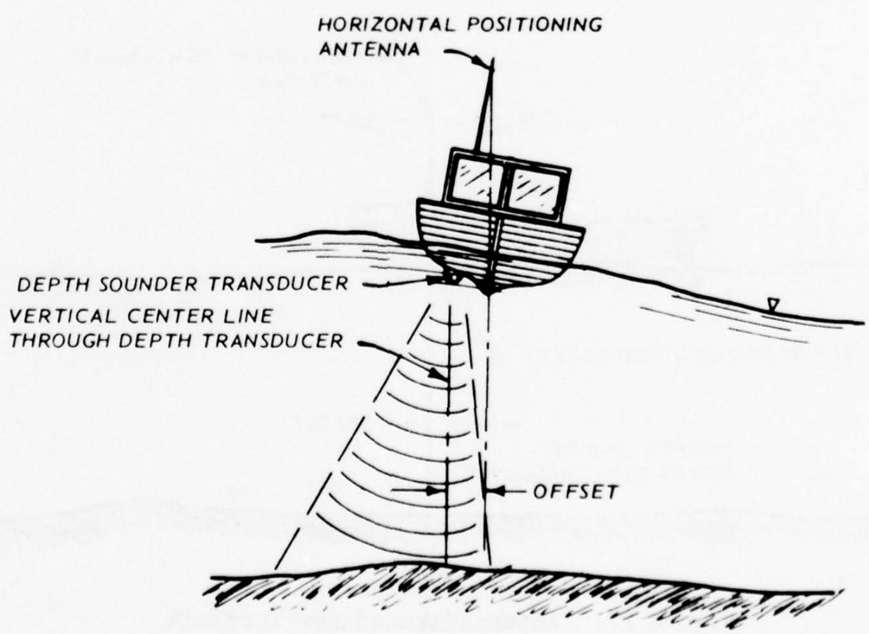


Figure 22. Antenna/transducer port/starboard offset due to roll

transducer. This type of offset is a periodic fluctuation about the mean water line and can be partially compensated for in data processing. It is also an example where the compromise on antenna height may be weighed between greater range or greater accuracy.

Depth transducer beam width effect on position

52. The depth measurement system can introduce a horizontal positioning error in survey data under some conditions. In the simplified sketch shown in Figure 23, the channel side slope will cause the depth measurement system to indicate a shallower depth at the channel boundary than actually exists. This effect is worse with steep side slopes, deep channels, and wide beam transducers.

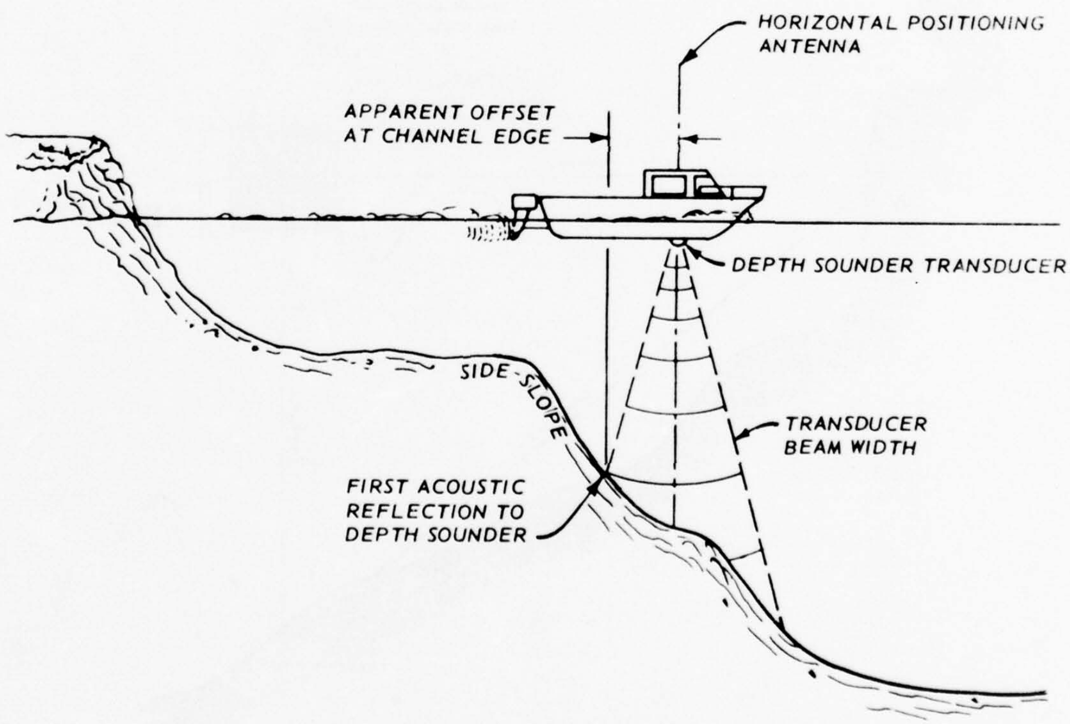


Figure 23. Horizontal position offset due to side slope effect

Geometry effects on accuracy

53. To obtain the best results from a positioning system, it is necessary to understand the effects of geometry on the accuracy of the

positioning system. Data from the best of the DME will be inadequate if the system is used without carefully checking the geometry of the operating area. When used with care, an electronic DME system can deliver static positioning accuracy that approaches the basic range accuracy of the equipment. Since nearly all of the Corps Districts use range-range positioning systems, this geometry will be considered first.

54. For a range-range positioning system, the horizontal accuracy of a given static data position depends on the angle of the range intercepts. The greatest position accuracy (for a given range accuracy) occurs when range vectors intersect at right angles. This condition is illustrated in Figure 24. With right-angle intercepts (α), the zone of

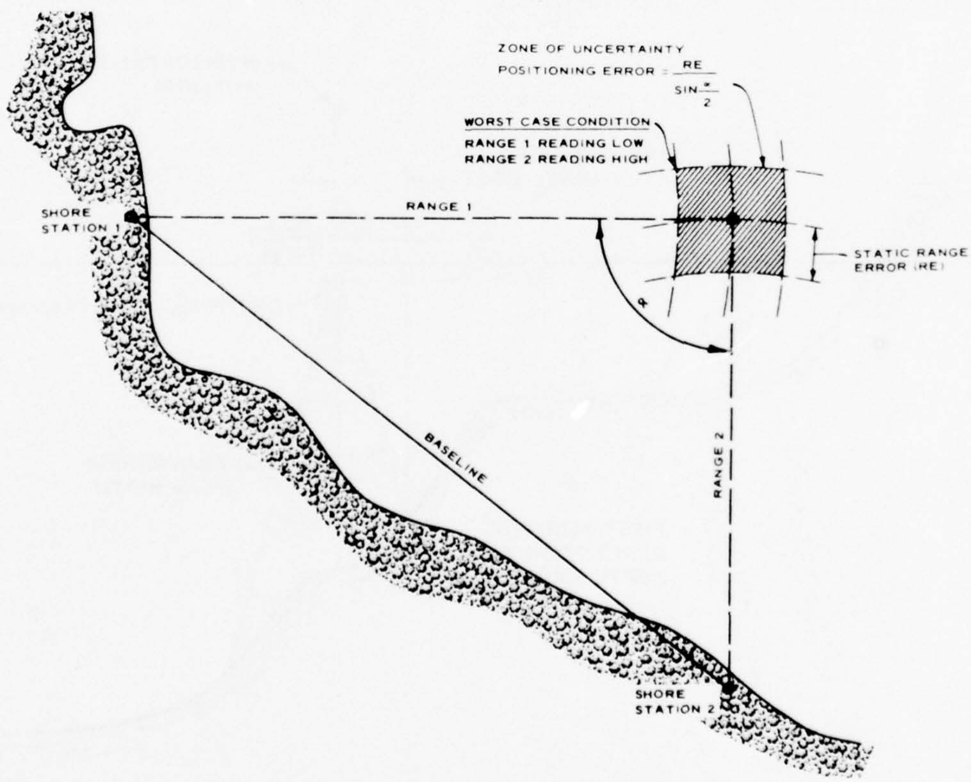


Figure 24. Range intercepts at 90 deg

uncertainty (the cross-hatched area in Figure 24) is approximately square and has worst case inaccuracies of approximately the square root of two ($\sqrt{2}$) times the basic range accuracy. The maximum inaccuracies occur at

the corners of the uncertainty zone where the range inaccuracies can combine to give the worst case condition. The geometry errors in actual practice may not be as severe as this example, but the worst case condition must be considered in order to be realistic about the potential errors.

55. As the angle of intercept of the two-range measurements moves away from 90 deg* in either direction, the zone of uncertainty becomes larger. For example, if the angle of intercept decreases to 30 deg as shown in Figure 25, the zone of uncertainty becomes a roughly rhombic-shaped figure (if equal error bands are ascribed to both ranges); the

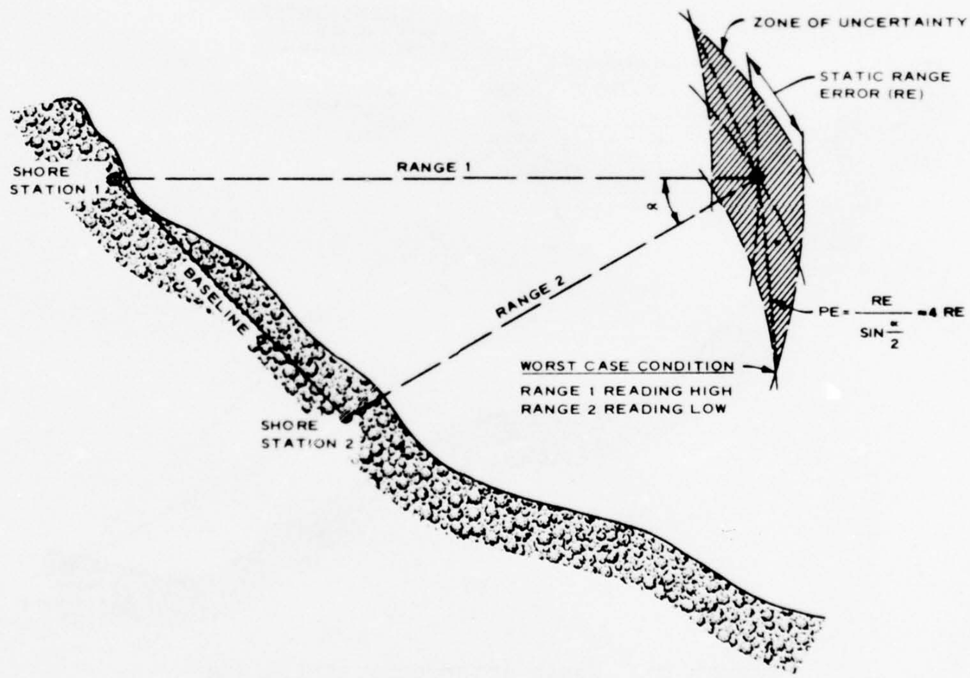


Figure 25. Range intercepts at 30 deg

worst case condition then shows the positioning error (PE) to be approximately the range error (RE) divided by the angle of intercept over 2.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units and metric (SI) units to U. S. customary units is presented on page 5.

For a 30-deg intercept, the PE is almost four times the RE. As the angle of intercept becomes smaller, the error increases rapidly. It should be noted that the maximum uncertainty occurs along one axis - not both, and this fact should be considered when selecting a shore (reference) station location, for errors in one direction are frequently of less importance than errors in another. For instance, cross-channel errors are usually more significant than longitudinal errors.

56. In an example where the angle of intercept is greater than 90 deg, the zone of uncertainty has the same shape as for angles less than 90 deg but with the worst case axis shifted. For an angle of intercept of 150 deg (Figure 26), the worst case error is the same as the

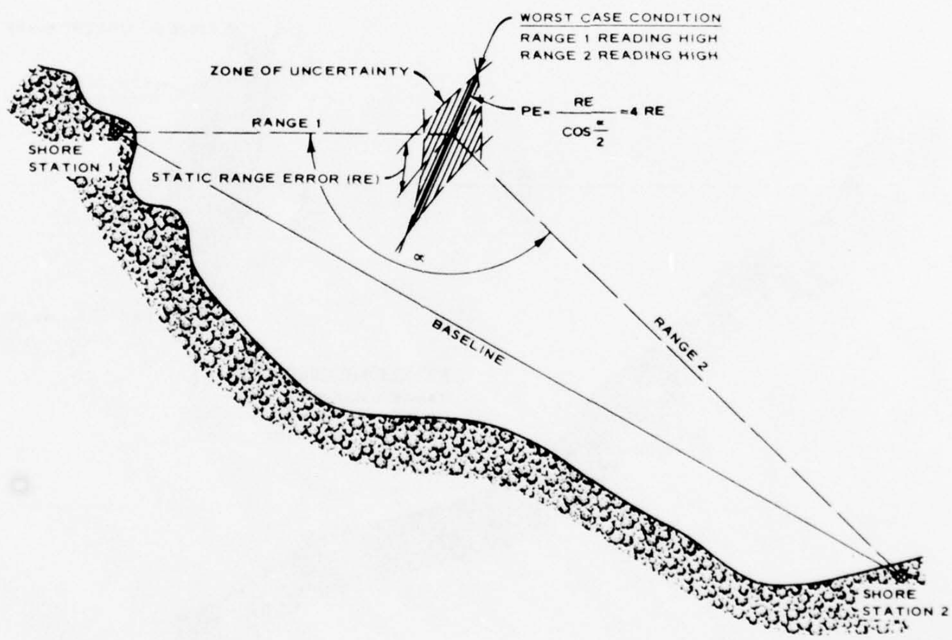

Figure 26. Range intercepts at 150 deg

worst case error at 30 deg but with the maximum error occurring at opposite corners of the uncertainty zone.

57. Some manufacturers recommend the 30- and 150-deg intercepts as general limits of operation for their system. For most purposes, the errors become excessive beyond these limits, and it is a realistic operational contraint. If an application requires higher accuracy, more time must be invested in maintaining geometry nearer to optimum.

58. A number of things can be done to optimize geometry for different types of projects. If a dredged channel is considered as an example, it is probable that the position of the edge of the channel can be a critical contractual point where dredging is by contract. Location of the channel edge requires measurement to a prescribed accuracy, while the calculation of volume is more dependent on resolution and repeatability of the positioning system. Figure 27 illustrates a simplified

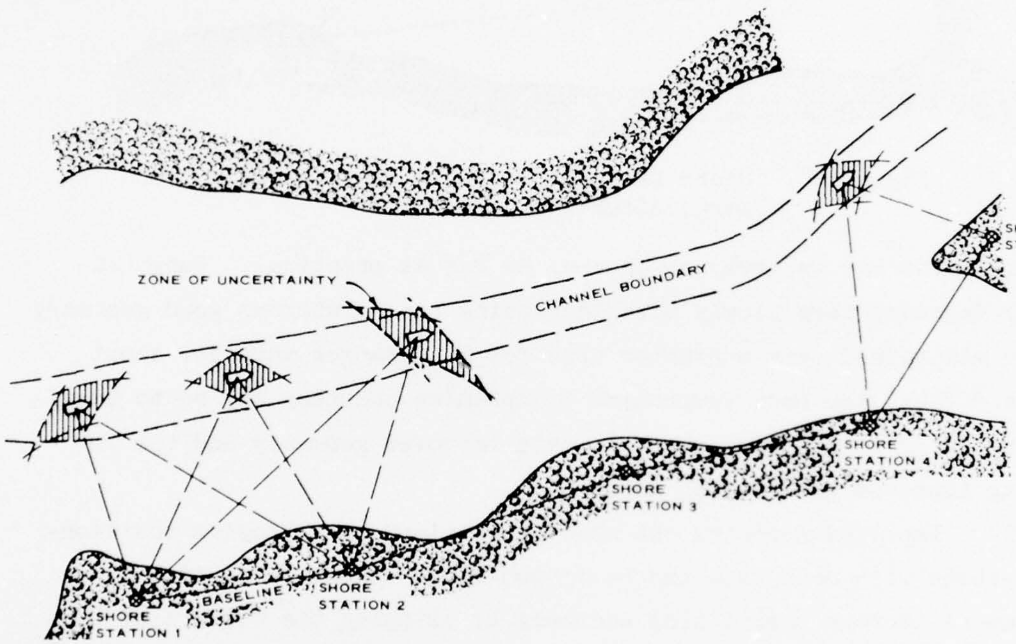

Figure 27. Shore station baselines approximately parallel to channel

channel with the baseline of the shore stations approximately parallel to the channel axis. Figure 28 shows a simplified channel with the baseline of the shore stations approximately perpendicular to the channel axis. The comparison of the zones of uncertainty in these figures revealed that the shore station arrangement in Figure 27 gives generally better cross-channel accuracy than Figure 28. The arrangement in Figure 27 is also better adapted to using a larger number of shore stations that can be switched into service as the survey boat progresses up the channel. Another way in which shore station location selection can be used to optimize positioning accuracy is to choose reference positions

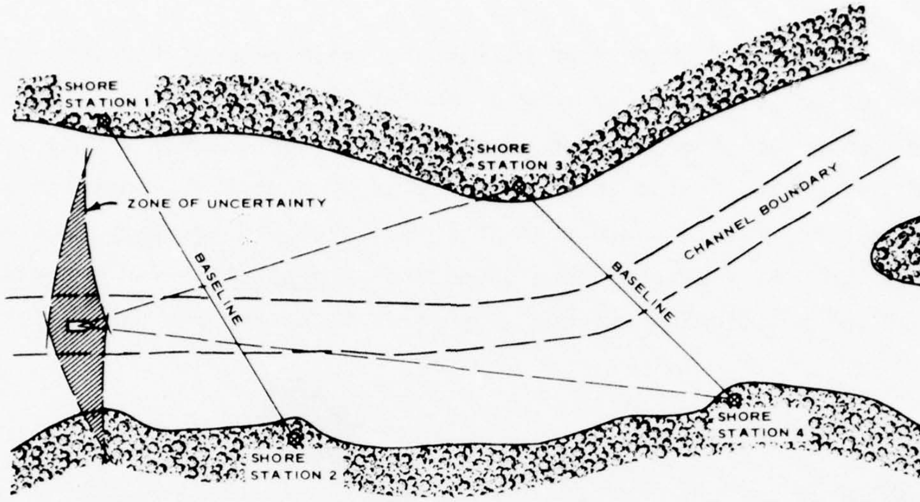

Figure 28. Shore station baselines approximately perpendicular to channel

set back from the waterway or channel as far as practical. Range accuracy degrades very slowly with increasing range, whereas good geometry can be maintained over a greater area for long ranges than for short ranges. Thus, the best compromise to optimize accuracy may be to sacrifice slightly in range accuracy to gain improved geometry and the resulting improved positioning accuracy.

59. Improved geometry can also be obtained by employing positioning systems with more than the basic two-range responders. Additional responders improve positioning accuracy by clipping the corners of the zone of uncertainty. The effect of using four responders simultaneously is illustrated in Figure 29. Additional shore stations of multirange DME will improve positioning accuracy so that it approaches the basic range accuracy of the DME. Several manufacturers of microwave DME offer models of, or options for, their equipment made for multirange use. Multirange systems are more costly than a basic range-range DME, but they offer considerable improvement in positioning accuracy and flexibility of operation. In addition to improved geometry, multichannel DME has the advantage of maintaining data collection in signal cancellation zones where a two-range system would fail or would require an alternate shore station position or shipboard antenna switching. Comments on the availability of multichannel options are included in

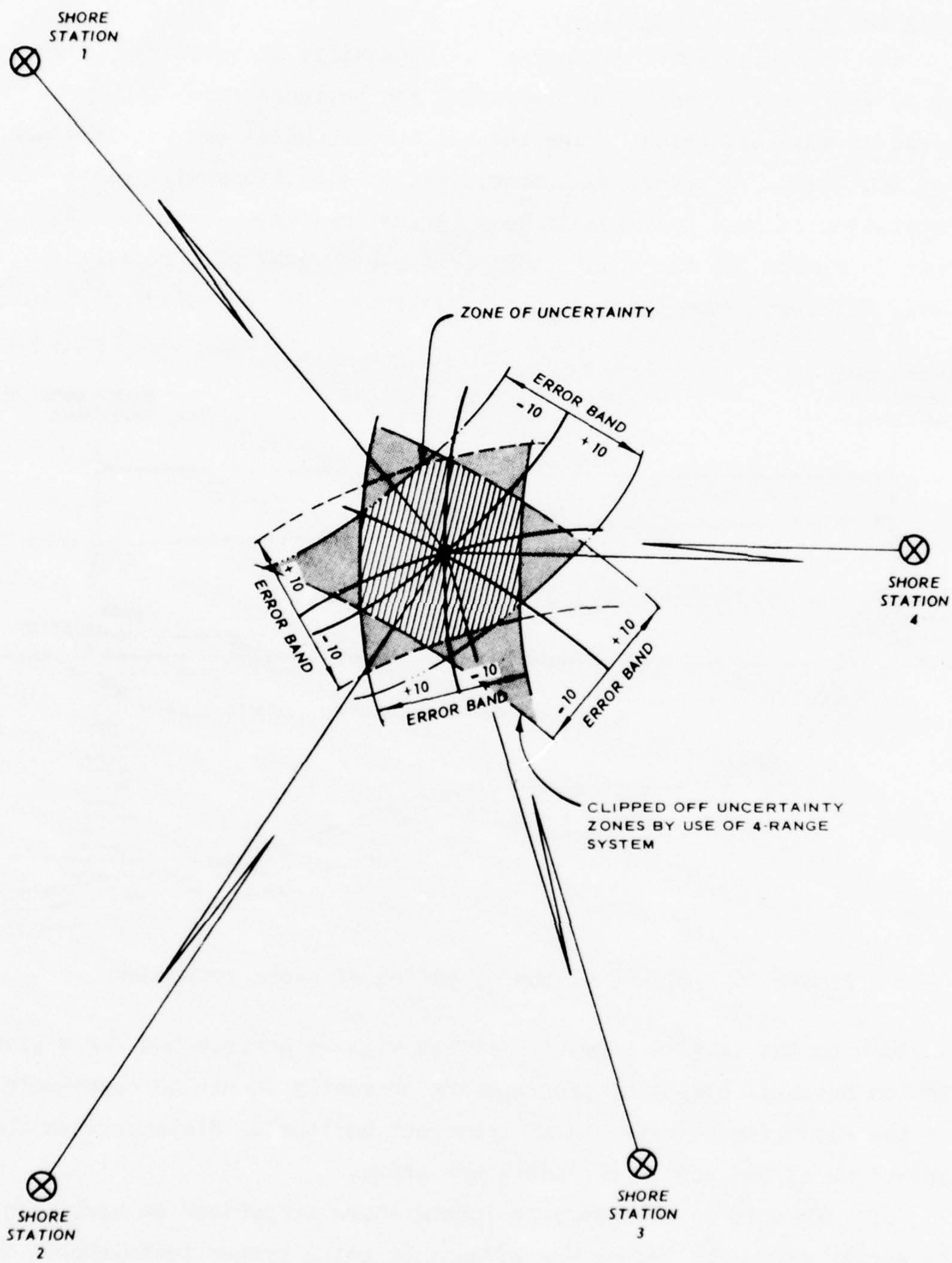

Figure 29. Multirange error reduction

Parts III and IV describing individual manufacturer's equipment.

Elevation of shore responders

60. Locating shore responders on high hills or buildings is one way in which the range of microwave DME can be increased. It may be forced in some situations where the hills surrounding the waterway are high and steep. However, high shore station elevations will cause the computation of boat position to be a three-dimensional problem. As shown in Figure 30, the slant range from a high hill will be significantly different from the horizontal distance. If the building or bluff

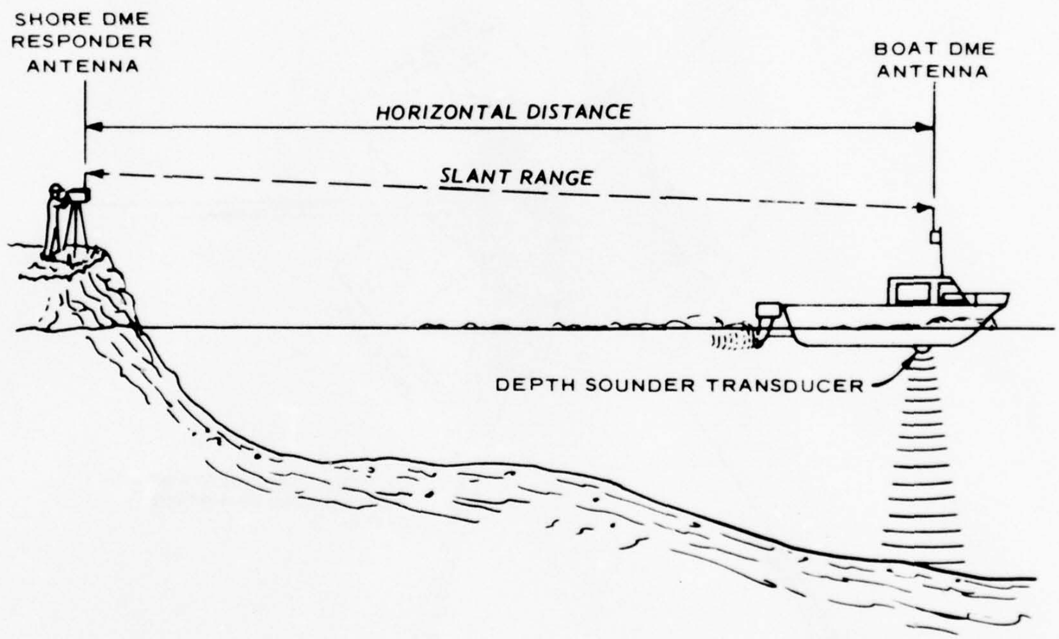

Figure 30. Effect of the elevation of shore responders

is close to the water's edge, the effect will be accentuated for a given station height. Computing programs are currently in use to compensate for the elevation effects and give correct horizontal distance when the elevations of the shore responders are known.

61. When it is necessary to locate shore responders on high points, the survey crews can reduce the effects by using proper techniques. As a general rule, the survey boat should avoid working close-in to a high antenna. If the survey crews keep the minimum range to at least ten

times the antenna elevation above the water, then the correction for slant range will be very small. For some purposes, the corrections may be held to acceptable limits with field-operating techniques to make computer corrections unnecessary.

Azimuth measuring accuracy

62. For a range-azimuth positioning system, the horizontal accuracy of a given static data position is inversely proportional to the distance from the shore station due to the angular error but is independent of the angular position within the field of view of the shore station operator. Figure 31 illustrates the zone of uncertainty of a

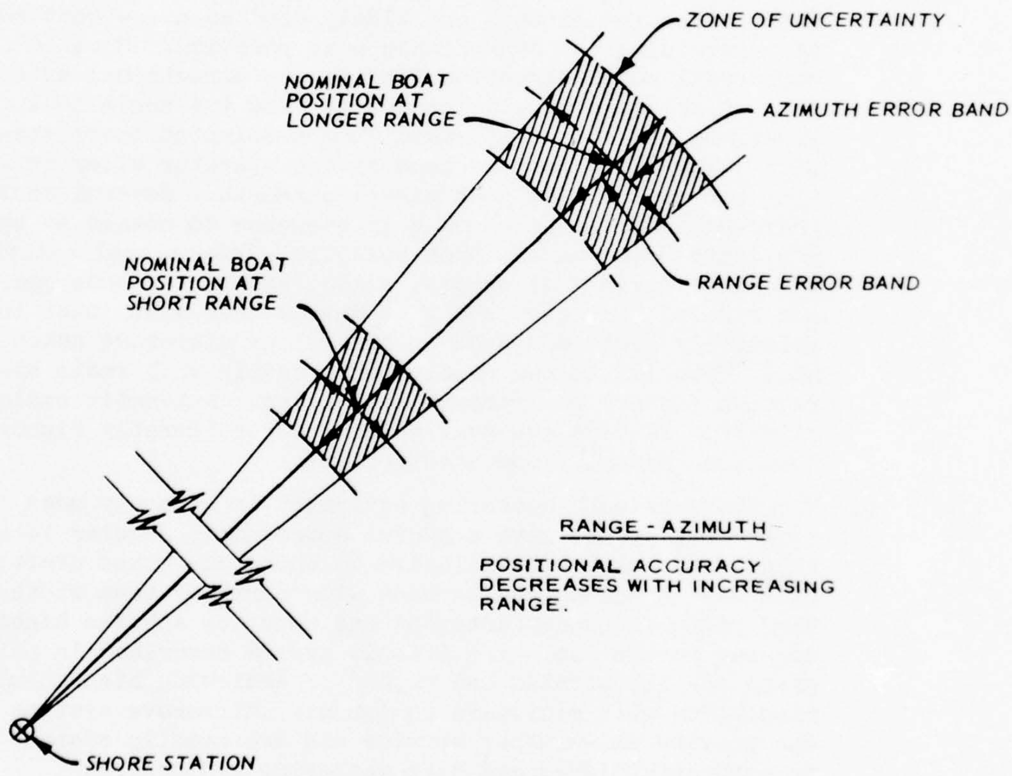

Figure 31. Range-azimuth positioning geometry

range-azimuth system and the increase in uncertainty with increasing range. The best accuracy with a range-azimuth system is achieved by keeping the ranges as small as practical, as minimizing range reduces the positioning uncertainty due to angular error. The choice of a range-azimuth shore station location with respect to a channel boundary should

consider the relative errors of the angular and range measurements. Wherever practical, the shore station position should be selected with the smaller axis of the zone of uncertainty perpendicular to critical channel boundaries.

Azimuth accuracy as
a function of technique

63. Azimuth may be measured by means of a number of techniques, each with advantages under a particular set of conditions. Figure 32 tabulates the following techniques used for determining azimuth for marine naviation:

a. Radio direction finders are widely used as a low-cost means of determining the approximate boat position. Most of the commercial radio direction finders use directional antennas, which are manually rotated to find the angle that gives maximum signal strength from a selected shore station. The angle must be read by the operator after setting the antenna for peak signal strength. Several shore radio beacons can be checked in sequence to obtain an approximate "fix" on the boat position. Directional antennas come in a variety of shapes, sizes, and performance characteristics, but even the best have a beam width that is relatively broad compared to optical or microwave antennas. This limits the resolution possible with radio direction finders to approximately 1 deg. Automatic radio direction finders are available at a considerably higher cost than manually operated units.

b. Microwave azimuth-measuring equipment is commonly used in radar displays to give a useful approximate angular location of the user boat relative to shore and other craft. Microwave antennas can be made with narrower beam widths than radio frequency antennas and thus can achieve higher angular resolution. The Artemis system described in paragraph 162 illustrates one method of achieving high angular resolution with microwave equipment. Microwave systems can provide all-weather service and are readily adapted to automatic high-speed data gathering and control applications.

c. Optical azimuth equipment offers the best accuracy available. Transits, as an example, are well-known to survey crew members. Most optical azimuth measurements are made by an operator visually sighting the target, but automatic optical tracking is possible. Examples of optical tracking systems are described later starting with paragraph 193. Optical instruments are line-of-sight, and operation

of this type equipment is impaired or prevented by fog, haze, rain, intervening structures, and vegetation.

d. Acoustic azimuth-measuring equipment is available for underwater work. Much greater underwater range capability is possible with acoustic equipment compared with optical equipment. Acoustic equivalents of more familiar optical and microwave equipment, such as radar, beacons, and DME, are available on the commercial market.

e. Inertial azimuth measurements use gyros and angular accelerometers as a reference. Gyrocompasses are a familiar and widely used example of this type equipment in marine navigation.

f. Magnetic compasses are widely used as an approximate measure of azimuth. Low cost, simplicity, and hundreds of years of acceptance make them an indispensable tool for marine operations.

Measurement Medium	Detection Method	Velocity Limit	Resolution Limit	Accuracy
Radio	Directional antenna	Mechanical equipment	1.0°	Limited by antenna beam width
Microwave	Directional antenna	Mechanical equipment	0.1°	Limited by antenna beam width
Optical	Collecting optics	Mechanical equipment	0.01°	Limited by propagation path uniformity
Acoustic	Directional antenna	Mechanical equipment	0.5°	Limited by propagation path uniformity and antenna beam width
Inertial	Gyro	Transducer response	0.01°	Time dependent drift
	Accelerometer	Transducer response	0.01°	Time dependent drift
Magnetic	Compass	Card damping	0.1°	Limited by uniformity of earth's magnetic field

Figure 32. Angle-measuring techniques

Accuracy as affected
by electronic interference

64. All positioning systems suffer from interference that can affect accuracy and, in some instances, cause operations to be completely disrupted. The most common types of interference for electronic systems are multipath, false targets, and electrical noise.

65. Multipath interference, due to energy reflection from the water surface, causes signals to arrive at the receiving antennas out of phase with the direct path signals. This type of interference, when mild, can cause scatter in the data and a degradation of the dynamic accuracy of the results. When severe, it may completely disrupt one channel of a range-range system and require relocation of shore responders or a vertical repositioning of the boat antennas.

66. False targets occur when electrically reflective structures, such as oil tanks and metal buildings, cause alternate signals to reach the receiving antennas. This effect is much like multipath, but it cannot be cured by vertical shift in the antennas. Relocation of shore stations is required to alleviate this problem.

67. Electrical noise may interfere with electronic positioning systems and cause effects ranging from accuracy loss to disruption of service. Radar interference can be a problem with microwave DME. With nonline-of-sight equipment, the problem can be high-voltage power lines.

Errors in measurement

68. Depth measurement. In addition to the positional errors in defining hydrographic survey accuracy, the depth measurement errors to consider are: (a) transit time measurement error, (b) velocity of propagation uncertainty due to temperature and salinity, (c) digitizing step size, (d) transducer beam width effects, (e) object detection resolution, (f) bottom acoustic reflectivity, (g) bottom geometry, (h) boat path relative to channel, (i) pitch and roll effects, (j) wave action, (k) tidal uncertainty, (l) river slope uncertainty, and (m) special bottom conditions where the transition from water to consolidated sediment is nebulous.

69. Time measurement. Depth measurement by acoustic reflection

is basically a measure of the transit time of a signal emitted from a transducer on the boat to strike a reflective surface and then returned to the boat. The errors introduced by the measurement of time can be negligible in a high-quality depth measurement system, but the other factors discussed in the following paragraphs are far from negligible.

Propagation velocity

70. Acoustic velocity of propagation is affected much more than electromagnetic energy by the temperature and density of the medium through which it is passing. Electronic DME may require minor corrections for temperature and humidity, but acoustic depth measurements are much more sensitive. Regular checks of the effective velocity of sound in a given waterway are necessary in order to achieve depth accuracy even halfway approaching the transit time measurement resolution. Calibration runs, usually referred to as bar checks, are regularly made by survey parties at appropriate times during the day. These checks should be made whenever the survey boat is moving into water where either temperature or salinity may have changed. Bar checks are made by lowering an acoustic reflector, such as a section of channel iron, to a known depth beneath the boat and adjusting the depth reading to correspond.

Transducer location

71. In addition to the basic transit time measurement corrections, a number of other factors must be allowed. The depth of the transducer below the waterline on the boat can be a direct reading correction on many modern depth measurement systems (Figure 33). Static correction, however, is not enough for high-accuracy depth measurement. It is necessary that the correction allow for transducer draft under the operating attitude of the boat as illustrated in Figure 34.

Tidal corrections

72. In tidal zones, the depth is referred to a reference level, such as mean sea level (msl). Since the surveys will in large part be made at levels other than msl, all readings must be dynamically adjusted for the changing water surface (Figure 35). Techniques currently in use by the Corps for tide correction are: (a) theoretical tide correction; (b) stationing a man at one or more shore sites to measure tide

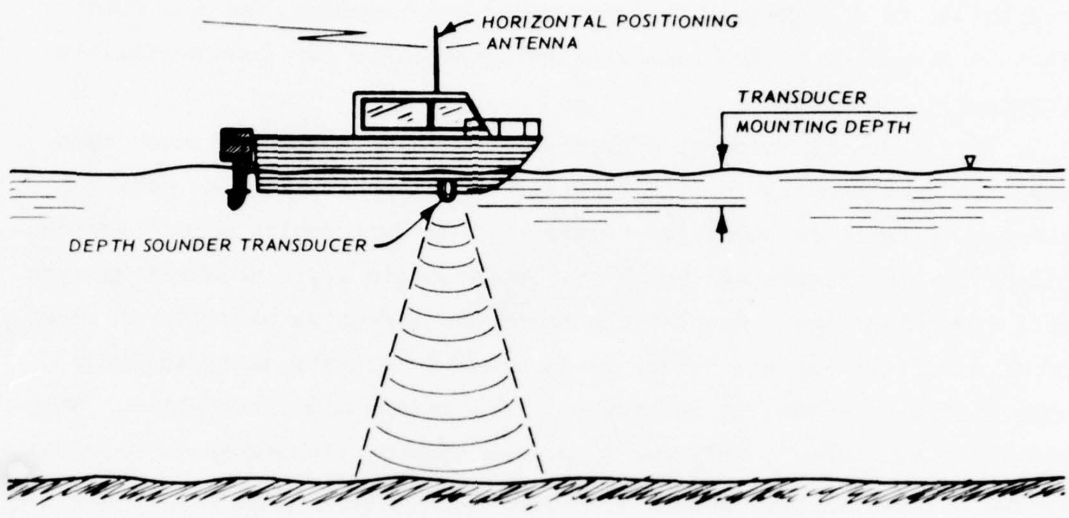

Figure 33. Draft correction for depth measurement

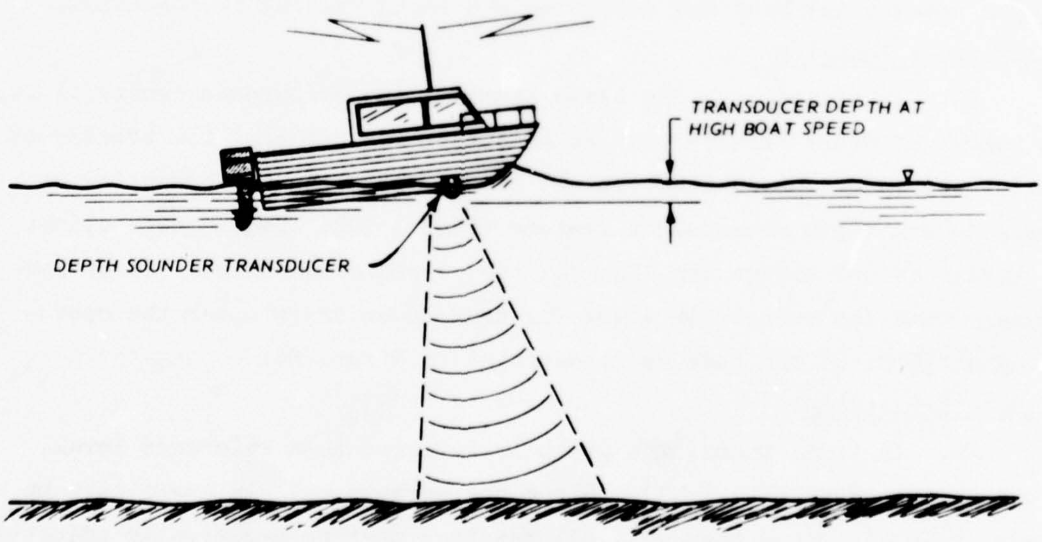

Figure 34. Boat-operating-attitude effect on depth measurement accuracy

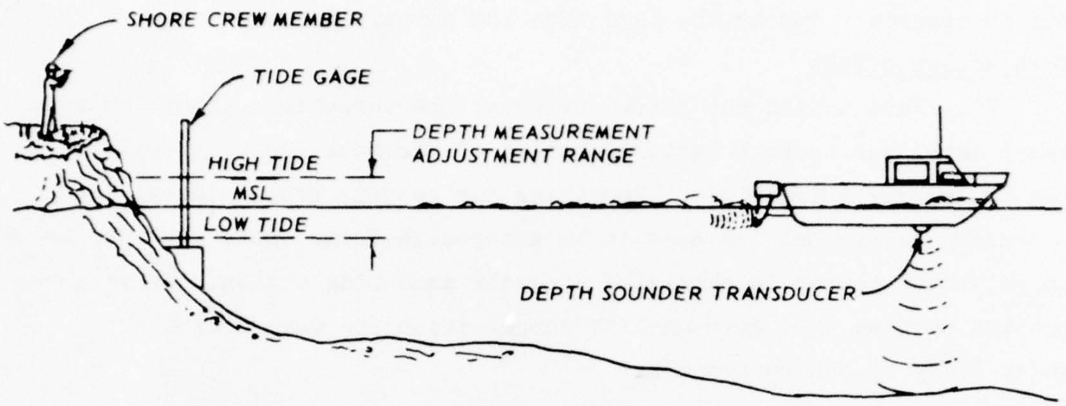

Figure 35. Tidal correction for depth measurement

and to radio tide corrections at periodic intervals; and (c) recording tide levels, and making corrections in the Automatic Data Processing (ADP) Center during data processing. Commercial equipment is available to automatically record water level changes.

River slope and stage corrections

73. River slope and river stage corrections (Figure 36) are inland waterway equivalents of tidal corrections. In most free flowing rivers, the changes are slow enough that one or two checks per day at a shore reference are sufficient. If surveys are being made downstream of a dam or control structure, a complete time history of the river stage

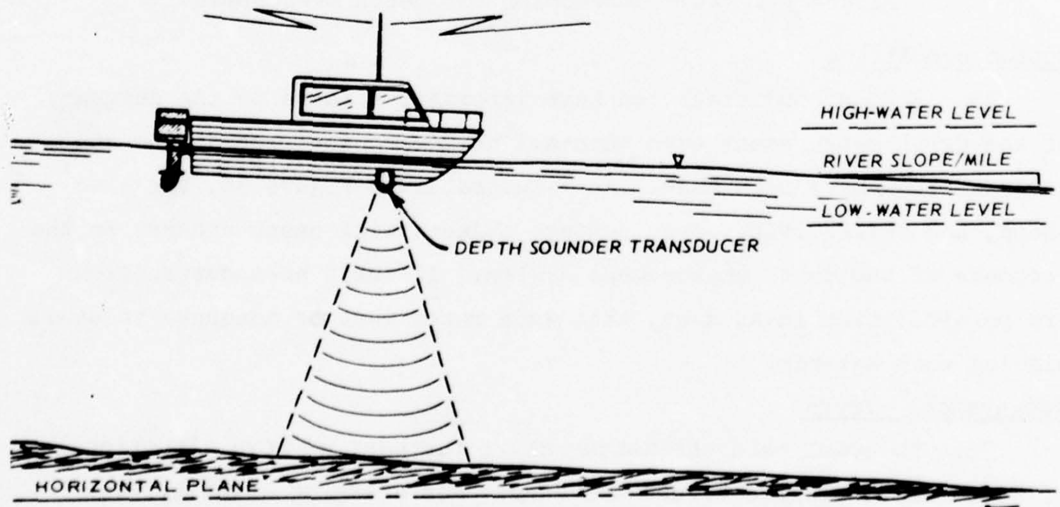

Figure 36. River slope correction

may be necessary during the days when the survey is run.

Wave action effect

74. Wave action can introduce severe perturbations about the mean water level due to both vertical motion of the boat and tilt angle of the transducer (Figure 37). Smoothing during data processing will be necessary to present the data in an acceptable form. Data rate can be an important factor in obtaining adequate smoothing action. Heave correction systems that give on-line compensation for wave action are under study by the government.

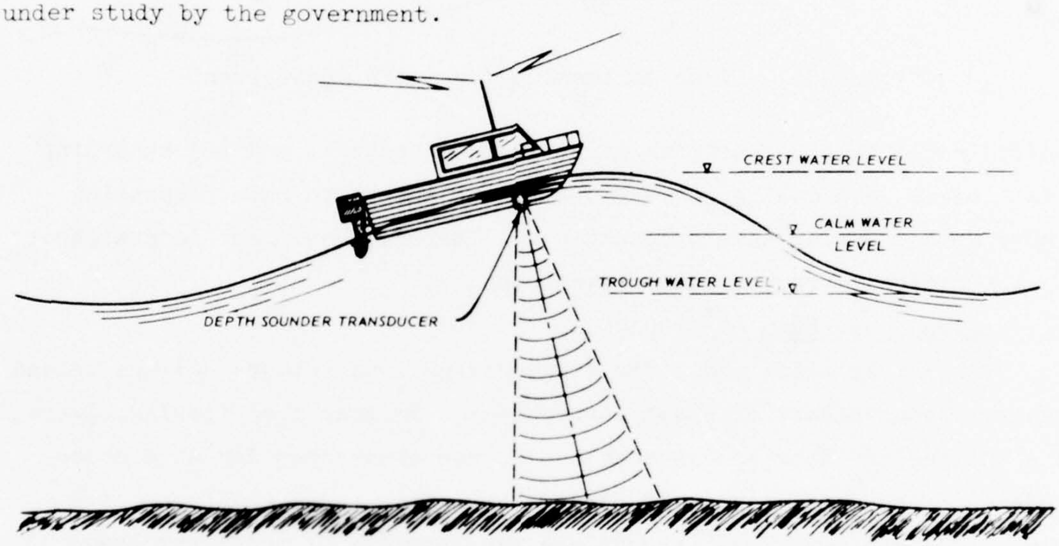

Figure 37. Wave correction for depth measurement

Bottom conditions

75. Bottom conditions can have important effects on the adequacy of the depth measurement even when all the foregoing precautions and compensations have been made. As illustrated in Figure 38, the size shape, and reflectivity of subsurface objects will cause changes in the response of the depth measurement system. If small area obstructions are possibilities in an area, then data rates must be adequate to avoid missing such hazards.

Nonphysical errors

76. To complicate the matter still further, we have situational effects that influence "true" accuracy. For dredging quantity, the time lag between material removal and survey can present a very

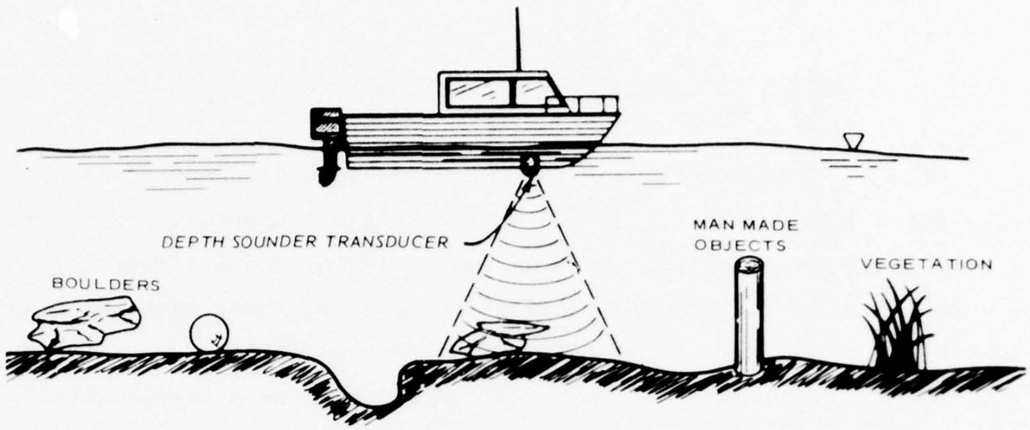

Figure 38. Bottom condition effect on depth measurement

significant error. Sediment in suspension can refill the channel to alter results. "Liquid" mud can flow into the dredge channel when the bottom equilibrium is disturbed by dredging. The natural shoaling rates can obscure the dredged channel dimensions.

<u>Summary of accuracy considerations</u>

77. Numerous measurement uncertainties have been listed to emphasize the need for a hydrographer to consider all aspects of an operation and also as a checklist for matching equipment to a specific job. The use of electronic equipment should, in general, considerably enhance the accuracy of a survey compared with manual methods. Due to faster survey rates, the time lag effects can be greatly reduced. Machine errors are also more predictable and consistent than are manual errors. Many times the human limitation errors are ignored in analyzing manual methods since these are so difficult to define and correct. It is beyond the scope of this report to attempt to analyze all of the error factors listed above; they are included primarily to aid in placing the positioning system error analysis in the proper prospective in the mind of the reader. Accuracy of the various commercial DME types is listed in the following sections as published in the respective manufacturer's sales literature. The experience of most Corps Districts using the equipment listed in Appendix C has been that the DME will generally meet the published specifications for static accuracy under idealized conditions.

PART III: NONLINE-OF-SIGHT COMMERCIAL SYSTEMS

78. The nonline-of-sight commercial equipment described can be used for accurate positioning of boats in inland waterways and coastal zones. Long-range systems, such as Omega, Loran, and Differential Loran, are not included because the inherent accuracy of these systems is unacceptable for the great majority of Corps survey applications. In some instances, a Loran receiver may prove very useful as a supplemental navigation aid for a Corps vessel operating in and out of a waterway equipped with precise positioning shore stations. An example of this might be a dredge that requires precise positioning in the dredged channel but needs only a coarse position at the dump area. The following paragraphs take individual systems potentially useful to the Corps and attempt to provide basic information to guide the reader in his selection for a specific application.

Teledyne/Raydist

79. The Hastings-Raydist Division of the Teledyne Corp. manufactures a radio frequency positioning system under the trade name Raydist. These systems operate on two frequencies, 1.6 and 3.2 MHz. These low frequencies permit nonline-of-sight positioning and correspondingly long ranges. Range is limited by the transmitter power antenna size and configuration, and path characteristics. Ranges of 200 miles over seawater and 20 miles overland are achievable under many of the normal operating conditions. An overwater path accuracy of less than 4 m can be achieved with a repeatability of approximately 1 m and resolution of 0.5 m. Overland signal transmission can introduce pattern shifts, but repeatability will still be good if the transmission paths are reasonably stable. Large changes in river or reservoir level can shift electronic patterns of nonline-of-sight systems, and the repeatability should be cross-checked under these conditions. Raydist systems can operate in three different modes (range-range, hyperbolic, and "T"), with the choice depending on application requirements and characteristics of the equipment.

Range-range mode

80. This mode of operation permits the measurement of the distance from the survey boat antenna to each of two shore station antennas--hence the name range-range. The range-range information, plus shore station coordinates, provides the data from which the boat position can be calculated. Range-range Raydist operates on the phase detection principle and is implemented by the system shown in Figure 39. This block diagram shows the basic technique used in a model DRS system.

81. A master transmitter (Fm) radiates a reference signal that is received by the two shore station receiver units. This reference signal is multiplied by two and shifted by a small percentage; the modified signals are then radiated from the transmitter section of each of the shore stations. These shore station signals are amplified and separated by the two sideband sections in the boat receiver. They are then referenced to the master transmitter signal, and the phases are compared. The measured phase of each signal determines the position of the boat within the wavelength (or lane) of the range-range pattern (Figure 40). The Raydist equipment sums the lanes traversed to give the total position. Figure 41 illustrates the equipment necessary to operate in the range-range mode.

Hyperbolic mode

82. When a Raydist system is operated in the hyperbolic mode, it is necessary to have a minimum of three shore stations. A boat equipped with a Raydist receiver, and within radio range of the shore stations, can receive signals from which the boat position can be determined. In the hyperbolic mode, only the difference in the range to a pair of the shore stations is measured at the boat receiver. As noted, only two of the shore stations provide a single family of lines of position hyperbolic in shape. An additional base station working with the reference transmitter station forms a second pair of shore stations from which a second set of hyperbolic lines of position can be derived. Thus, with three stations, the pair of hyperbolic lines of position generated intersect in a unique pattern (Figure 42) and allow the boat position to be

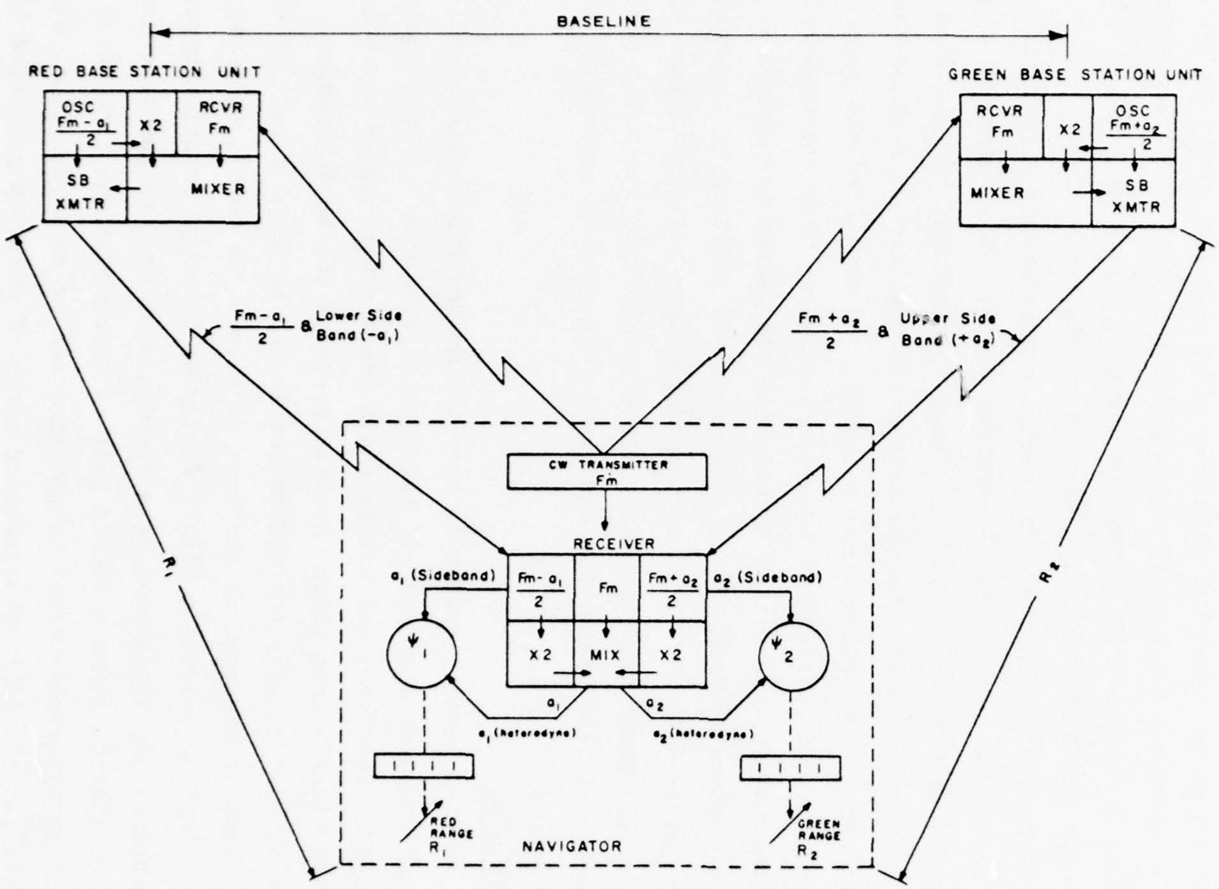

Figure 39. Raydist range-range functional diagram

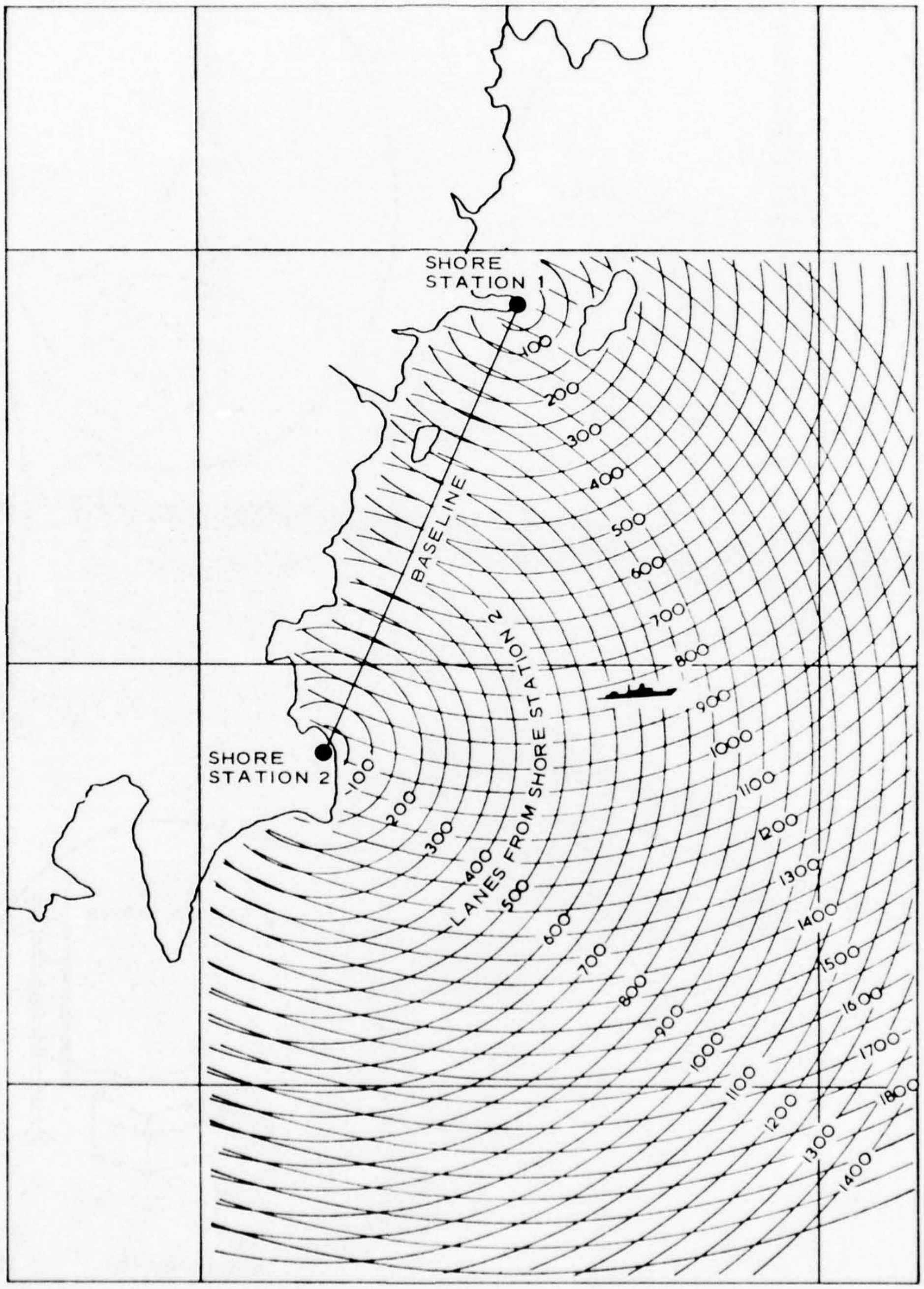

Figure 40. The range-range pattern

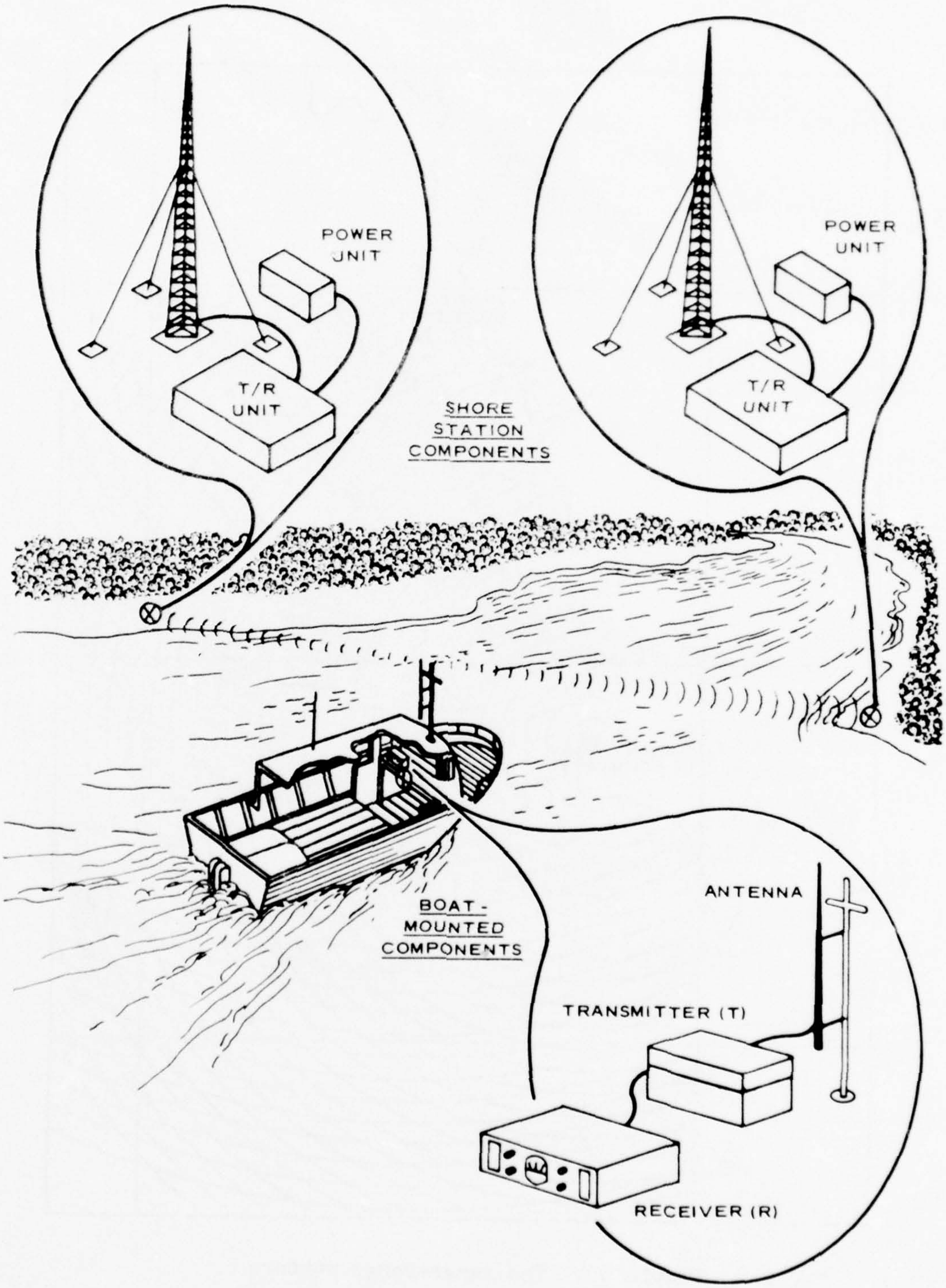

Figure 41. Components of Raydist range-range positioning system

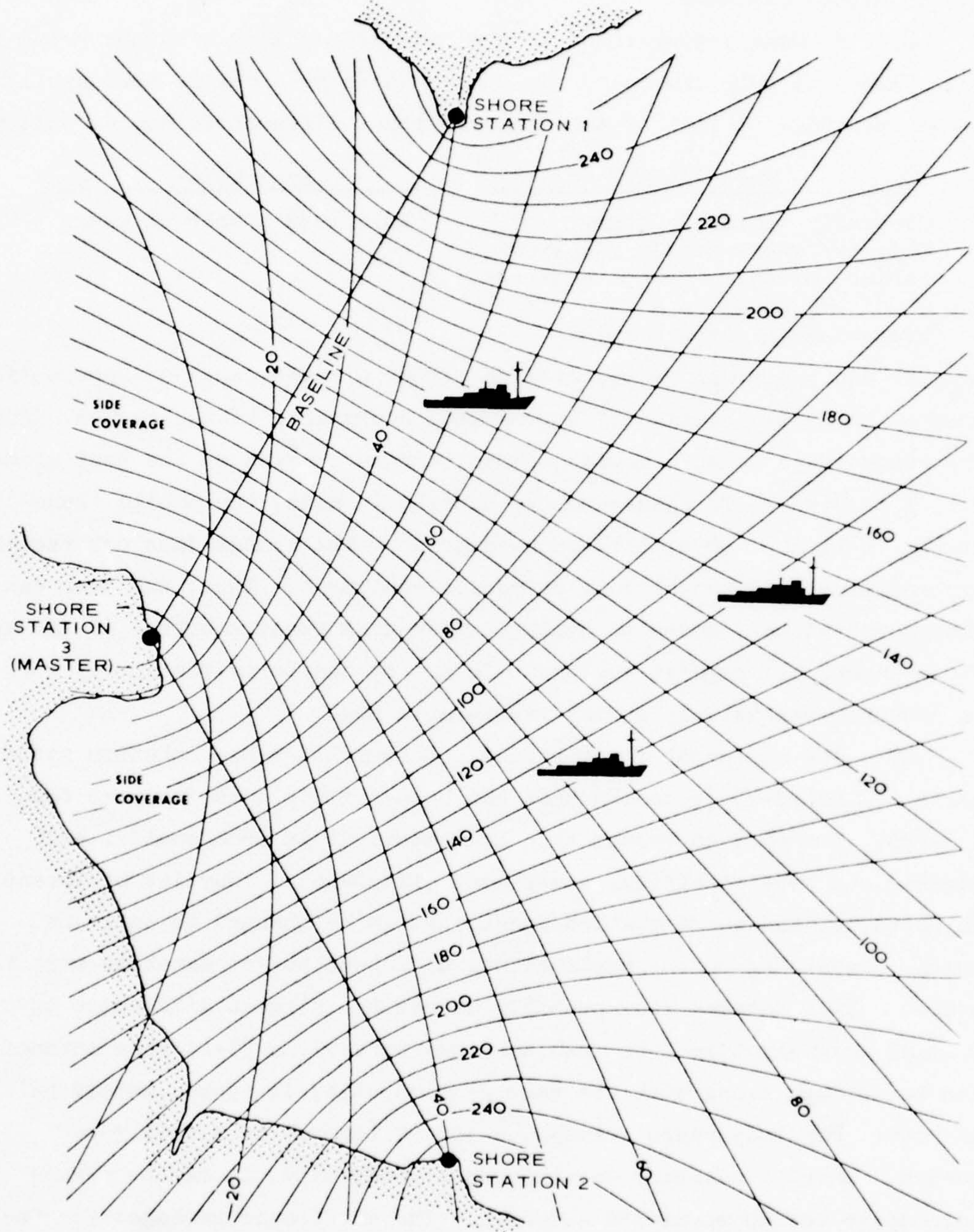

Figure 42. The hyperbolic pattern

calculated. Figure 43 illustrates the equipment necessary to operate in the hyperbolic mode.

83. A summary comparison of the range-range mode with the hyperbolic mode may help the reader to decide which mode can be best applied to a given job. A list of the most important differences are as follows:

Range-Range	Hyperbolic
Generally better accuracy	Unlimited number of users
Only two shore stations needed	
Easier for operator to interpret and use range data	
Transmission paths simpler	

Raydist equipment can be operated in either a range-range or hyperbolic mode by suitable location of appropriate components of the system. For the range-range mode, a mobile transmitter is located on the boat along with a receiver. To change to the hyperbolic mode, the mobile transmitter is located at a third shore station. The change does not require any modifications to the base or mobile equipment. Thus, the user can change operational modes to suit specific work requirements. As far as it is known, all Raydist equipment in use by the Corps for survey work is operated exclusively in the range-range mode.

84. The equipment for the model DRS Raydist radio location system is an all solid-state design that has been field proven for more than 7 years. Compared to vacuum tube equipment, it is much smaller and lighter and uses electrical power more efficiently. Raydist equipment is portable, and shore station locations can be changed to suit job needs. Depending on the application, different height antennas will be needed. This antenna size probably causes the biggest difference in station assembly time. For medium-range surveys, a 35-ft whip antenna can be set up, along with the base station unit, in approximately half an hour. For long-range surveys, a 100-ft tower will normally be needed. Where a waterway is surveyed periodically, it may be advantageous to set up permanent antennas. The electronic packages for the shore stations can be moved quickly from one location to another and connected to the permanent antennas as needed.

85. Raydist also offers equipment for a "T" system, a modified

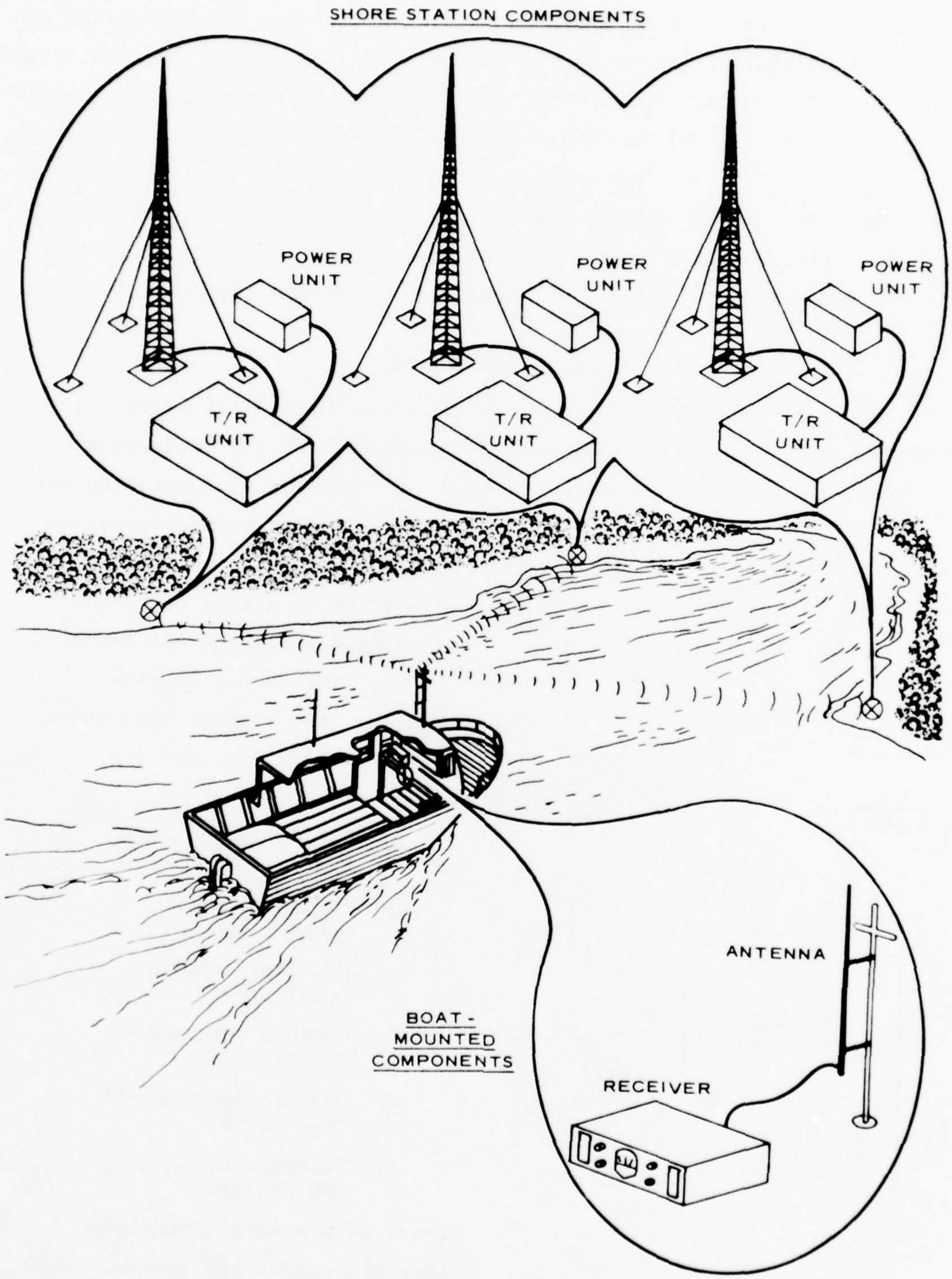

Figure 43. Components of Raydist positioning system working in hyperbolic mode

hyperbolic system with an improved pattern geometry. The "T" system requires four shore stations compared with three for regular hyperbolic mode and two for the range-range mode. This system has advantages for multiboat applications, but the DRS system is more economical for single-boat use. No districts are now using a "T" system due to the higher cost of equipment and larger number of shore stations that must be installed. Other options available include: (a) equipment for multiboat operation in the range-range mode, and (b) equipment to permit lane identification.

Teledyne/Geotech

86. The Geotech Division of the Teledyne Corp. will supply an integrated hydrographic survey system complete with all hardware and software necessary to start operations. In addition to furnishing the system, Teledyne/Geotech services include installation on the survey boat and training of personnel in system use and maintenance.

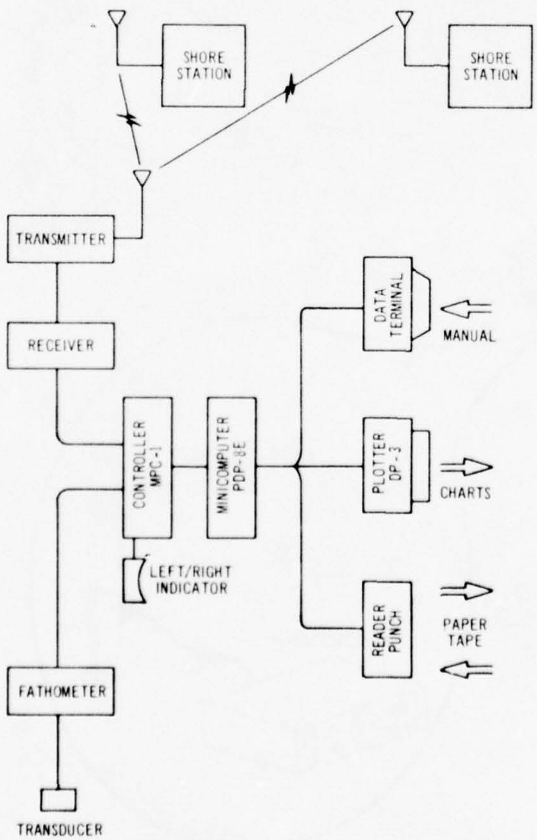

Figure 44. Geotech hydrographic survey system, Model IHSS-100C

87. The Geotech hydrographic survey system, designated the Model IHSS-100C, has the following components:

- a. Raydist Positioning System DRS-H.
- b. Raytheon Depth Sounder DE-719B.
- c. DEC Minicomputer, Model PDP-8E.
- d. Geotech Controller MPC-1.
- e. Houston Instruments Plotter DP-3.
- f. Teletype or LA-30 DEC Writer.

Figure 44 presents a function block diagram of the system.

88. The Raydist positioning system and the Raytheon Fathometer provide automatic input signals to the controller for system operation. Manual input and stored information are communicated to the system by means of the DEC writer, front panel controls, and paper tape reader. Output of the system is presented by paper tape, data recording, plotted charts, data terminal printed record, and a visual display in the left/right indicator.

89. The MPC-1 controller contains the interface for converting the Raydist receiver output to computer compatible format, as well as a digitizer to change the Fathometer signals to computer compatible format. In addition, the controller has the versatility to accept input signals from associated equipment other than those listed if the need arises.

Decca/Hi-Fix

90. Decca Survey Systems, Inc., markets a nonline-of-sight positioning system under the trade name Hi-Fix. The transmitters in a Hi-Fix system emit continuous waves (CW) signals in sequence, all sharing one radio frequency. The system thus requires only a single-frequency allocation. Signals from the master and each slave are, in turn, phase compared in the receiver on the boat to give a radio fix of position. Range is limited by the transmitter power selected and propagation path characteristics. Using the higher power transmitter option permits operating ranges up to 200 miles over seawater and roughly 20 miles overland. Repeatability of positioning when operating with overland paths will be somewhat dependent on surface conditions. Large changes in water level on rivers and reservoirs will probably introduce significant shifts.

91. The Hi-Fix system can operate in either a range-range mode (Figure 45) or in a hyperbolic mode (Figure 46). The specifications for this system are as follows:

- a. Operating frequency: 1.6 to 2.1 MHz.
- b. Range: 50 to 100 miles with 10-W transmitter/31-ft antenna; 100 to 200 miles with 40-W transmitter/31-ft antenna.
- c. Accuracy: ± 1 m under optimum conditions.
- d. Power: 24-V DC.

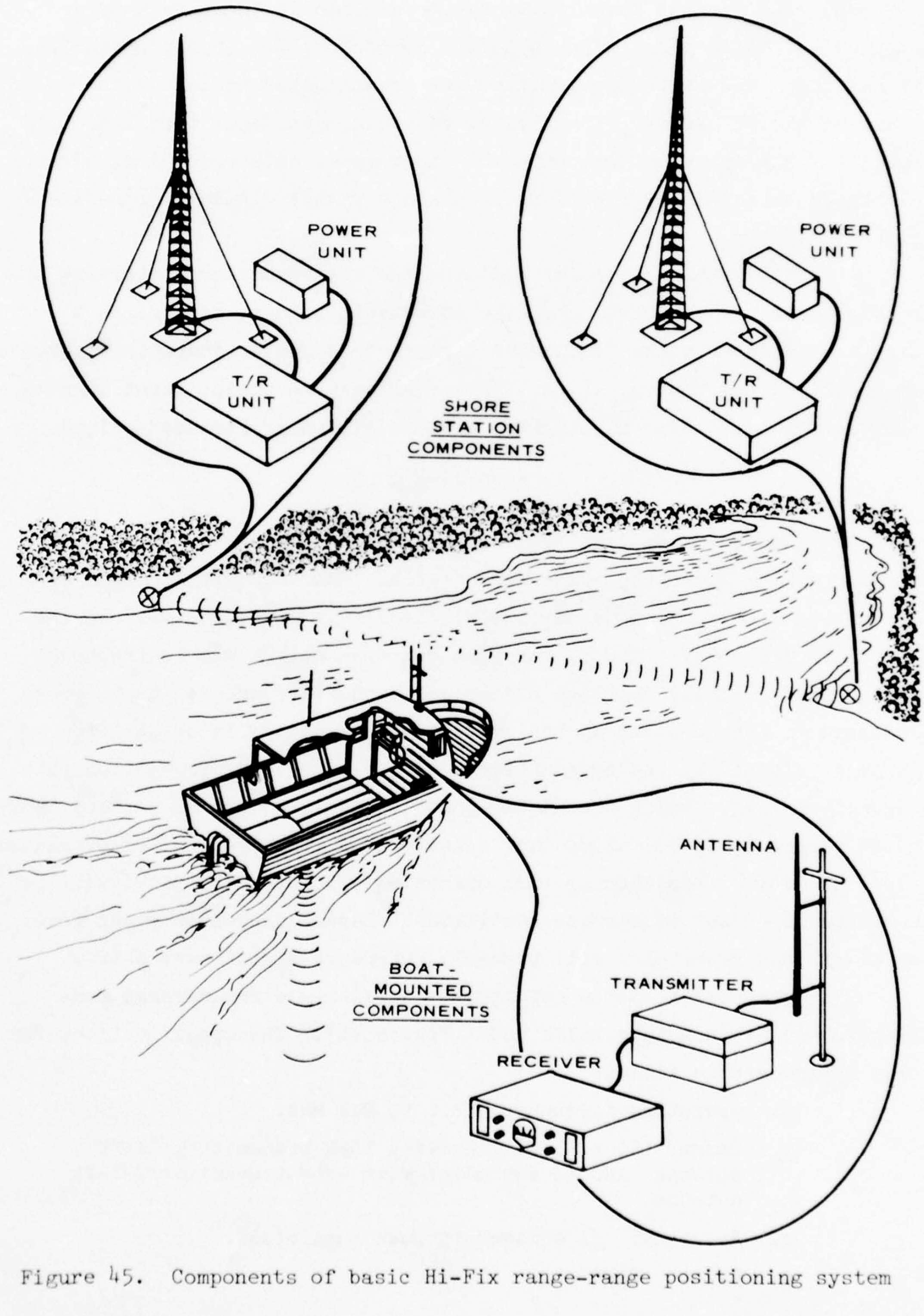

Figure 45. Components of basic Hi-Fix range-range positioning system

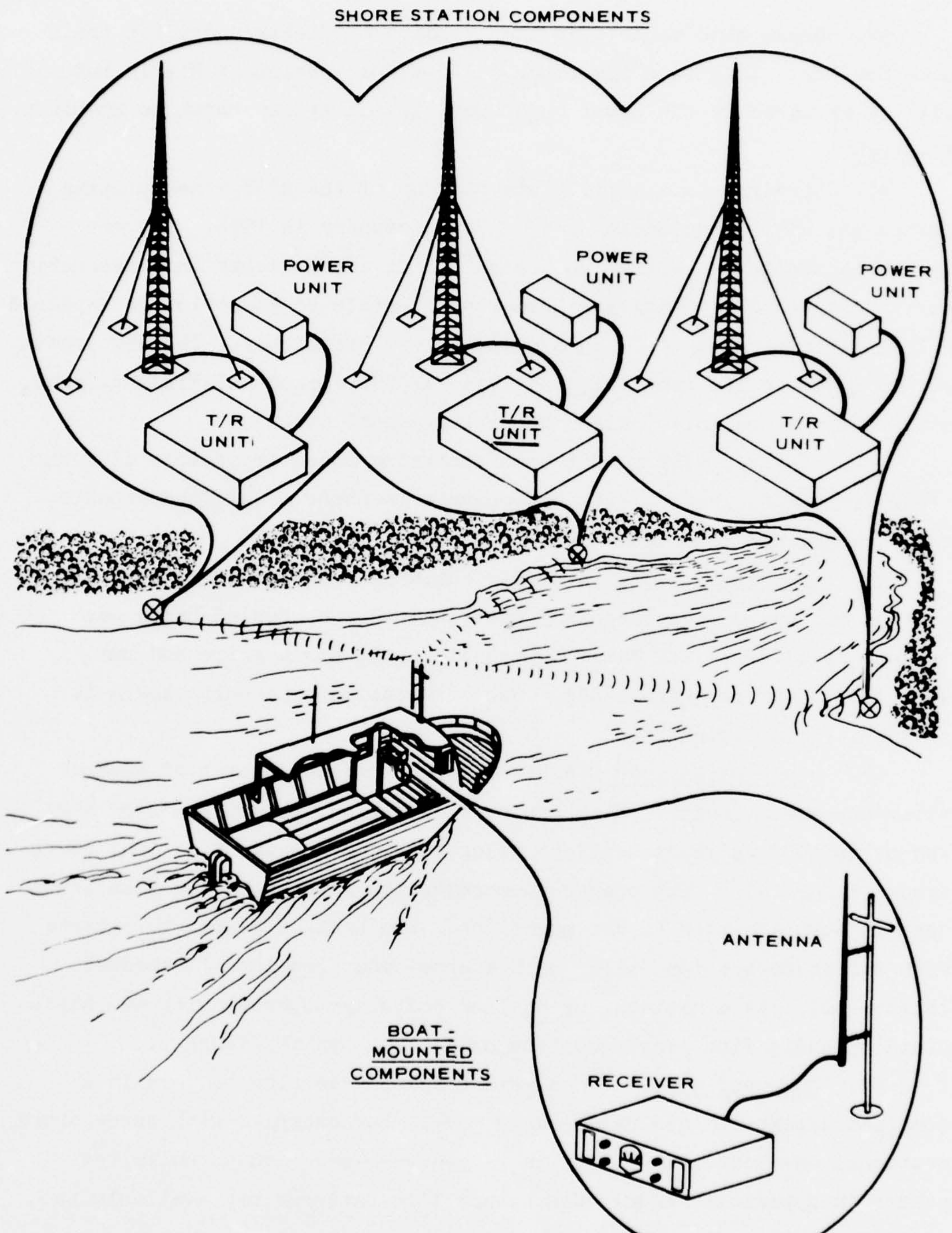

Figure 46. Components of Hi-Fix positioning system working in the hyperbolic mode

92. Decca also markets another version of Hi-Fix under the trade name Sea-Fix. This is a low-power solid-state version of Hi-Fix but will be replaced by the newer model positioning system known as Hi-Fix/6.

Hi-Fix/6

93. Hi-Fix/6 is a solid-state version of the Hi-Fix positioning system and was scheduled for sale in this country in 1976. The new design incorporates several very significant improvements in construction and in operating capability. Use of solid-state construction is expected to reduce maintenance and improve electrical efficiency. The new system will operate in the same frequency band as the current Hi-Fix and, thus, will retain a nonline-of-sight operating capability.

94. Hi-Fix/6 will permit some operating modes impossible with the older equipment. This system can operate in three modes: hyperbolic, range-range, and compound.

95. Hyperbolic mode. A Hi-Fix chain can consist of a prime shore station and up to five secondary stations. Any number of boats can operate receivers. The basic hyperbolic chain has a prime and two secondary stations (Figure 47). The six-station hyperbolic chain is illustrated in Figure 48.

96. Range-range mode. A Hi-Fix/6 system can consist of several alternate arrangements. With one boat operating, it can focus on any two of up to five shore stations using both coarse- and fine-lane receptions (Figure 49). The coarse-lane reception identifies the fine lanes that in turn are used to get precision. Two boats are able to operate with two shore stations using both coarse- and fine-lane receptions (Figure 50). As a maximum, up to four boats can operate with two shore stations using fine-lane reception only, as shown in Figure 51.

97. Compound mode. The Hi-Fix/6 system can also be used in a combined hyperbolic and range-range mode. For example, with three shore stations, one boat can operate in range-range mode and an unlimited number in hyperbolic mode. Coarse and fine patterns are available to all users. With three boats operating in range-range mode and an unlimited number in hyperbolic mode, all users are limited to fine patterns only.

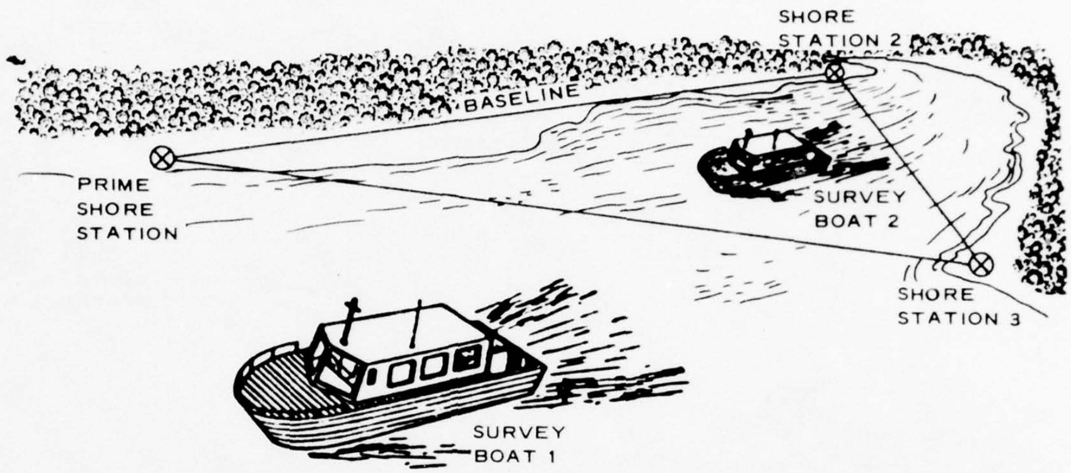

Figure 47. Basic three station-three baseline Hi-Fix 6 system operating in hyperbolic mode

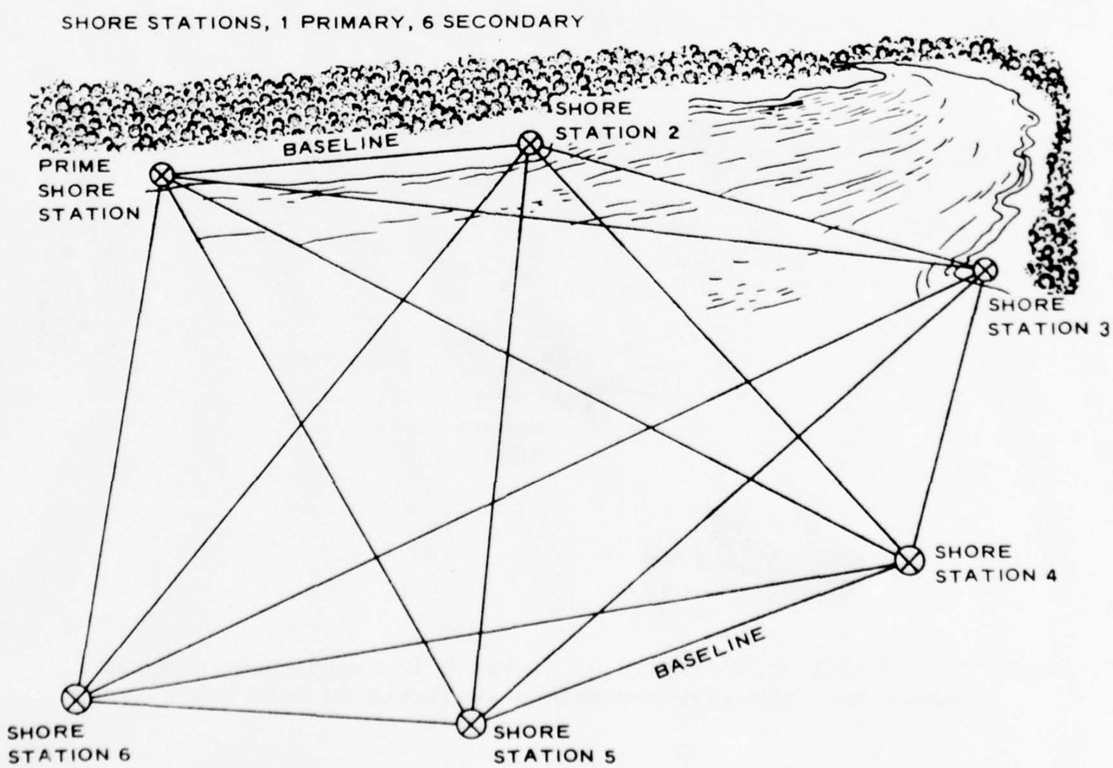

Figure 48. Six station-fifteen baseline Hi-Fix 6 system operating in hyperbolic mode

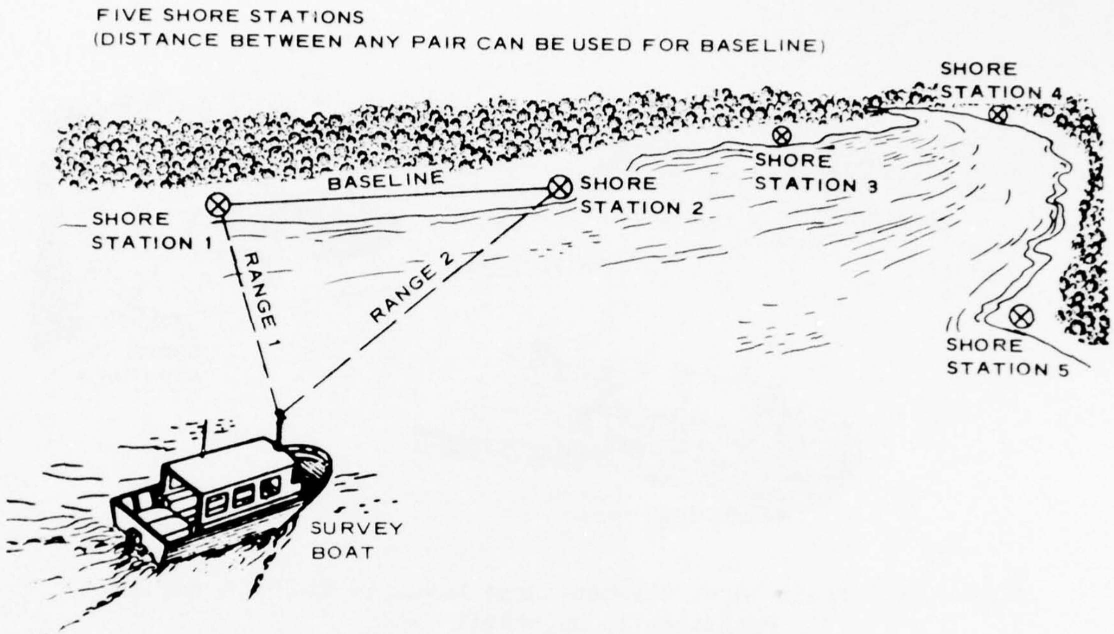

Figure 49. Single-boat operation of Hi-Fix 6 in range-range mode

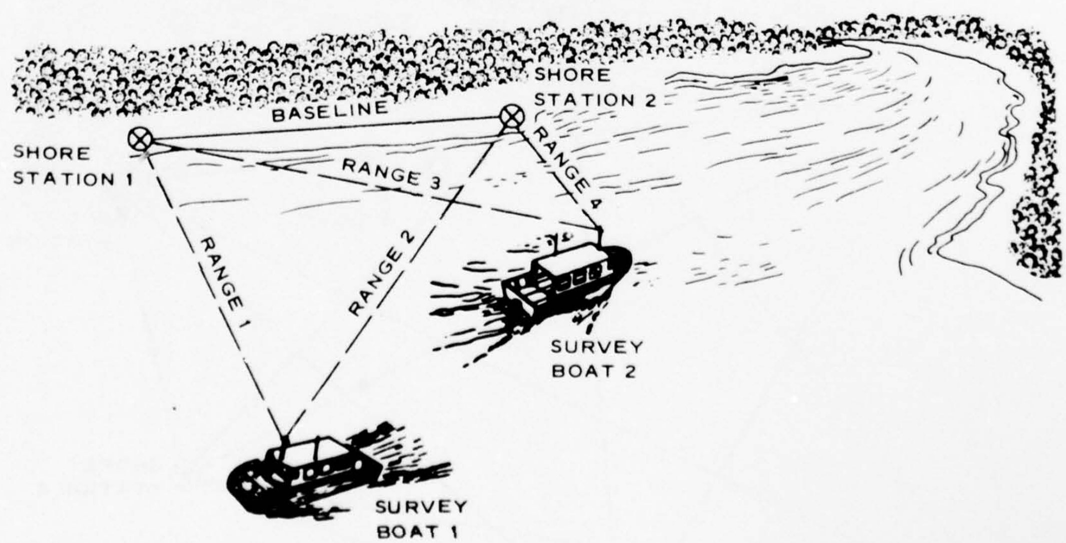

Figure 50. Miltiboat operation of Hi-Fix 6 in range-range mode with coarse- and fine-lane receptions available to both boats

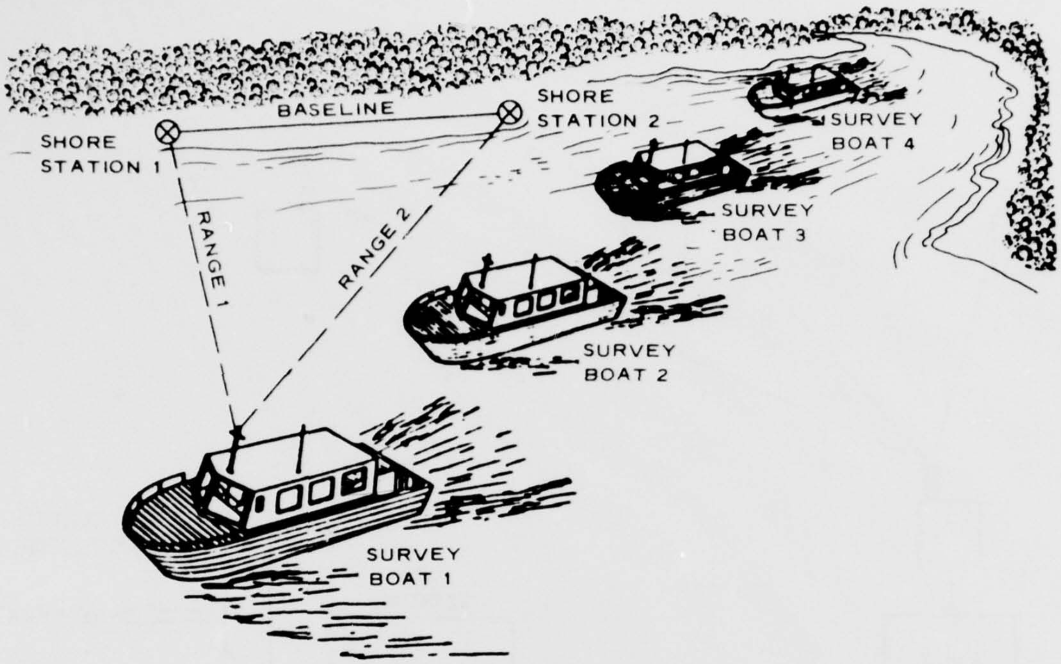

Figure 51. Multiboat operation of Hi-Fix 6 in range-range mode with only fine-lane reception available to all boats

Autocarta

98. In addition to the Hi-Fix positioning systems, Decca offers a selection of companion units that can be configured in various ways to assemble a hydrographic survey system adapted to a specific project. The Autocarta is a minicomputer-based system for real-time positioning and recording. A basic Autocarta system consists of (a) a minicomputer, (b) a data terminal, (c) a plotter, and (d) a left/right display unit. Optional components are different-sized plotters and paper tape reader/ punch. Figure 52 shows a basic Autocarta system coupled with a basic Trisponder system and a digital depth sounder.

Hydrocarta/Hydrotrac

99. The Hydrocarta Corp. offers a nonline-of-sight positioning system under the trade name Hydrotrac. The Hydrotrac positioning system operates in the 2-MHz band at a frequency selected by the customer. This system may be used in either a range-range mode or hyperbolic mode.

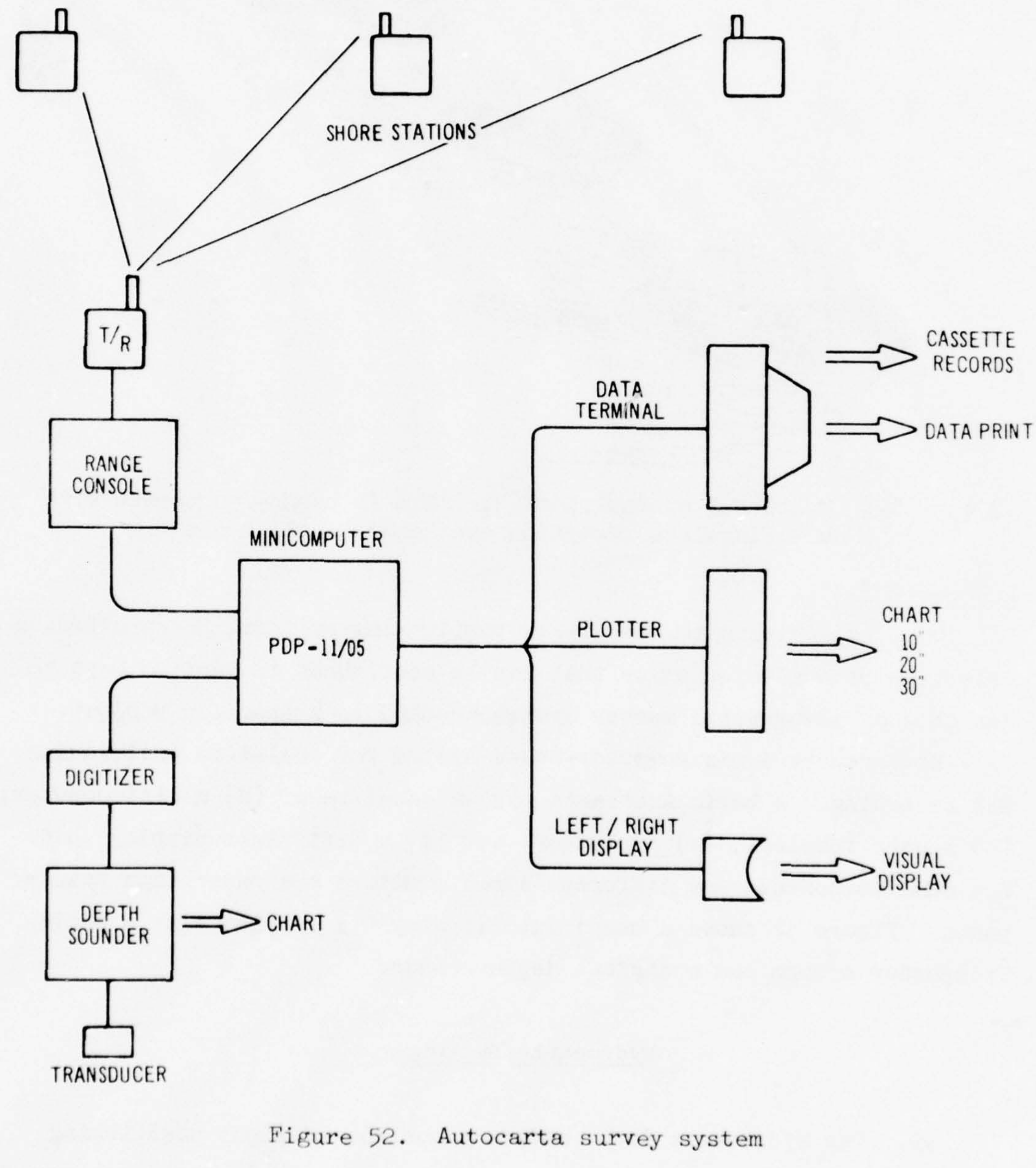

Figure 52. Autocarta survey system

Output of the Hydrotrac receiver is serial digital for easy interface with associated equipment, such as computers and data loggers. Figure 53 shows the equipment needed for operation in the range-range mode. Special features of the Hydrotrac system include:

- a. Circuits to greatly reduce lane loss due to lightning.
- b. Circuits to greatly reduce lane loss due to sky-wave interference.
- c. All solid-state equipment is for improved reliability.

100. The Hydrocarta Corp. places primary interest in the minicomputer-controlled hydrographic survey systems that they market. Considerable company effort has gone into software development to attain the highest on-line plotting performance. System components are standard industrial products, which can be readily maintained.

Cubic/Argo

101. The Cubic Industrial Corp. offers a nonline-of-sight positioning system under the trade name Argo. An Argo positioning system operates at one customer-selected frequency in the 1.6- to 1.8-MHz band. This operating frequency allows over-the-horizon positioning in the open sea and makes it possible to position boats in sinuous river channels where microwave positioning systems may be more time-consuming to work with. The system is designed for operation in a range-range mode (Figure 54). As a special feature of Argo, up to eight boats may operate simultaneously from one pair of shore stations (Figure 55).

102. Cubic specifications for the Argo positioning system are listed below:

- a. Maximum range: 400 nautical miles (daytime).
- b. Range accuracy: 1 m.
- c. Lane width: 80 to 90 m.
- d. Operating frequency: 1.6 to 1.8 MHz.
- e. Transmitted power: 60-W peak.
- f. Data rate: once per 2 sec.
- g. Data range: to 9999.999 lanes.

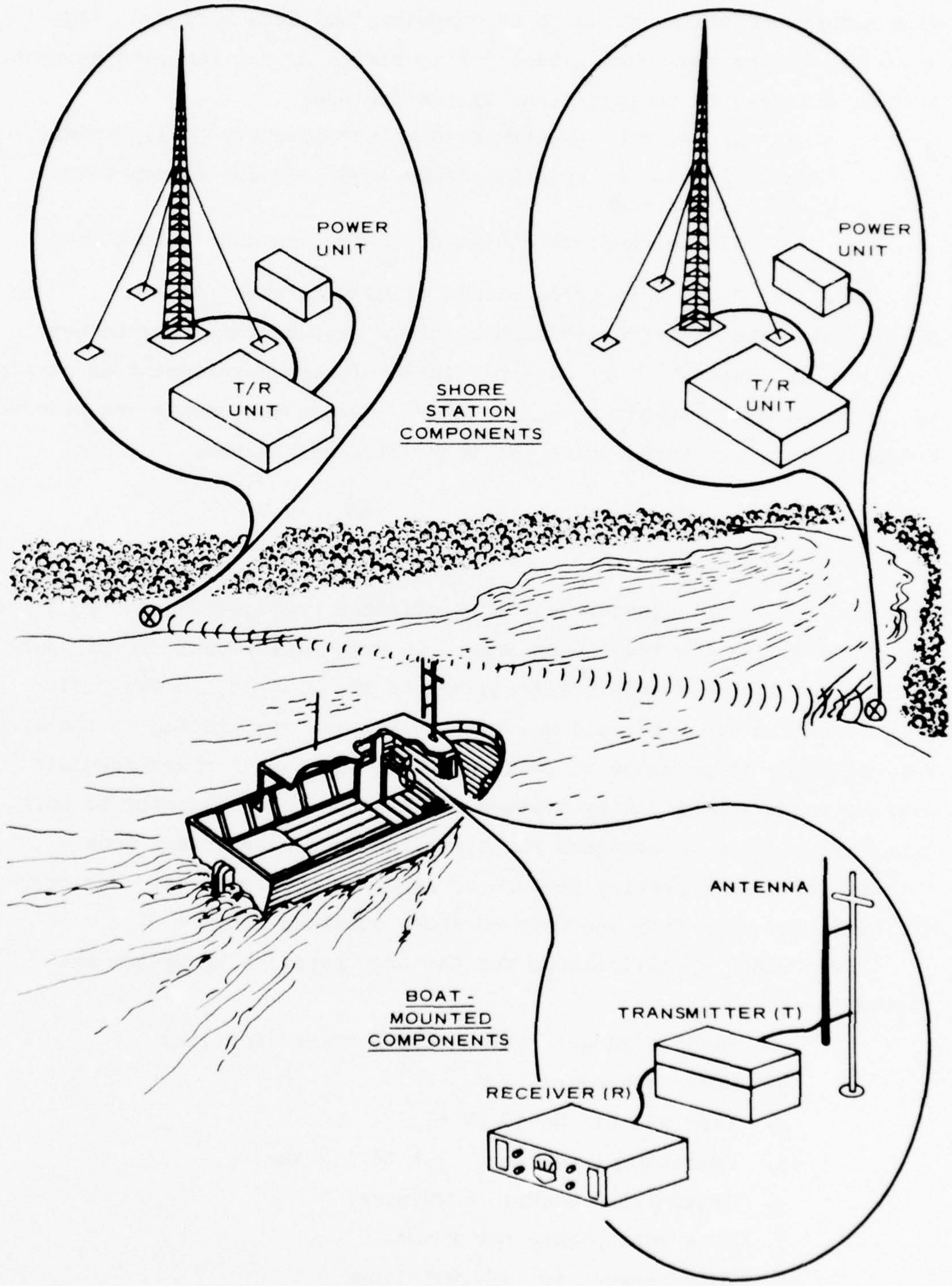

Figure 53. Components of Hydrotrac range-range positioning system

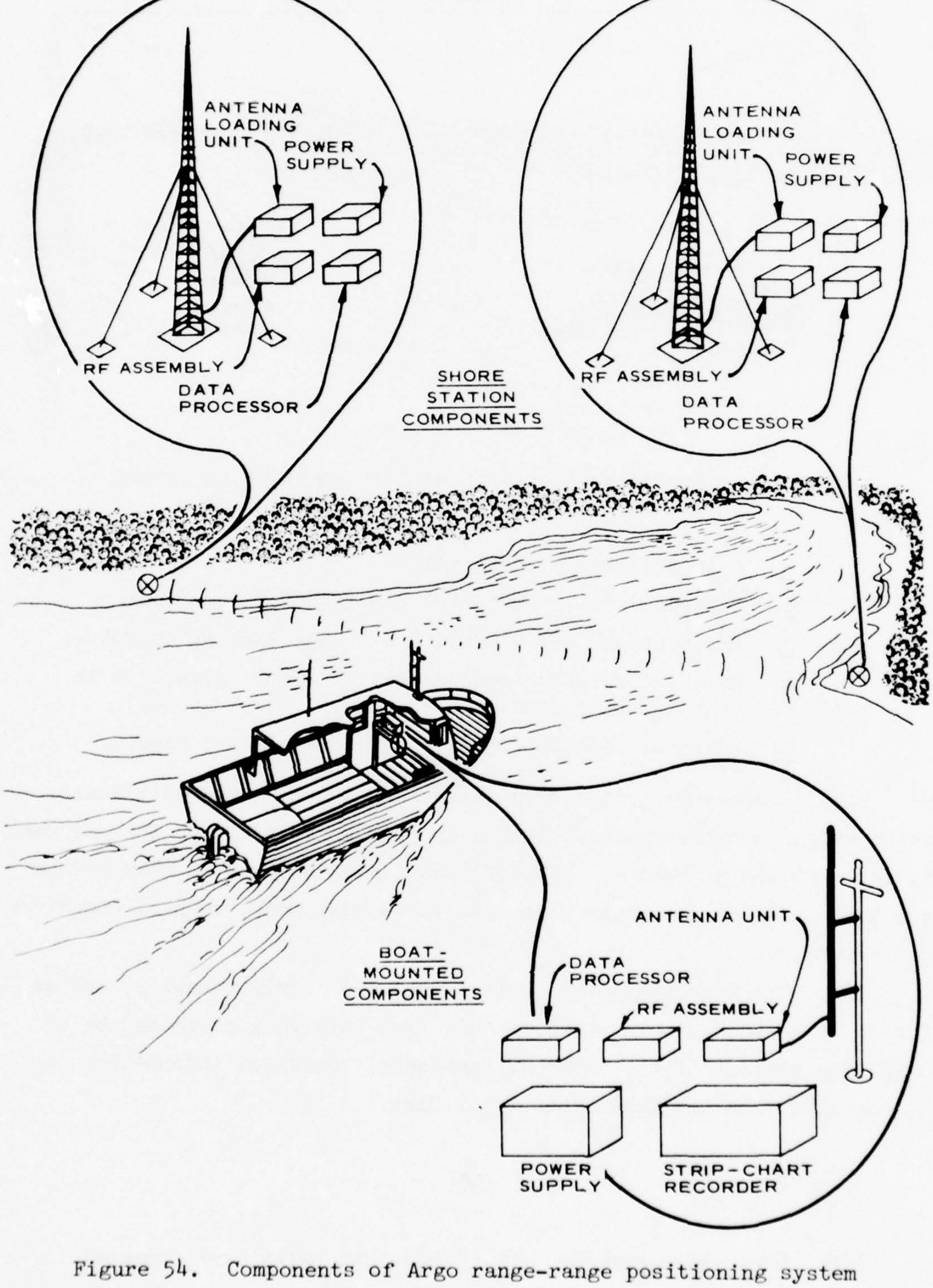

Figure 54. Components of Argo range-range positioning system

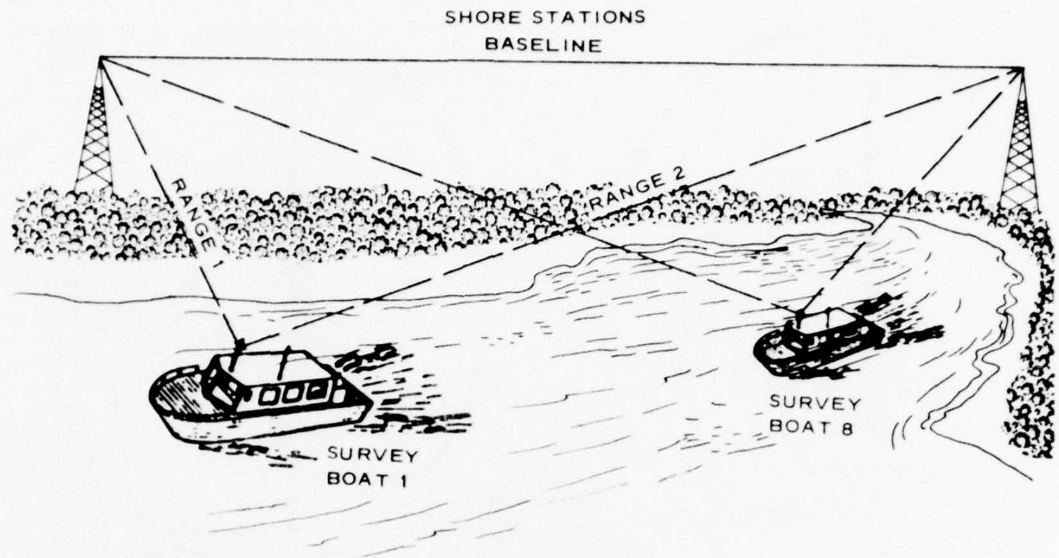

Figure 55. Multiboat operation of Argo positioning system with up to eight boats in range-range mode

h. Data smoothing: four modes

i. Data interface: parallel digital (BCD) and analog.

j. Input power: 24-V DC at 6 A or 115 V/60 Hz at 200 W.

k. Size and weight: mobile station--four units, 110 lb (total); base station--four units, 80 lb (total).

l. Antenna: mobile--35-ft ship; base--100-ft tower.

103. Components of the Argo system are packaged in individual units weighing approximately 20 lb each to make them easier for one man to carry aboard or ashore. Both BCD and analog outputs of this system are available for interface with associated equipment, such as computers and recorders.

104. The Argo system has been introduced fairly recently, and as far as it is known, no systems of this type have been purchased by an operating element of the Corps of Engineers. Detailed information can be obtained from the Cubic Industrial Corp.

OMI

105. Ocean Measurements, Inc. (OMI), has built developmental

model radio frequency positioning systems using ultrastable oscillators for reference sources at the shore stations and on the boat. The ultra-stable oscillators eliminate the need for a reference transmitter in the system and make it possible to have an unlimited number of boat receivers operating simultaneously.

106. The OMI systems are not yet advertised commercially. A current price exceeding $100,000 will probably discourage potential users until cost reductions occur.

PART IV: LINE-OF-SIGHT COMMERCIAL SYSTEMS

107. The electronic line-of-sight positioning systems described are considered to be of potential use to Corps offices. Aircraft-type navigation aids and specialized military systems technically in this category are not addressed since these systems are outside the scope of this report. The following paragraphs discuss only those systems with accuracy and physical characteristics adaptable for Corps use.

Motorola/Mini-Ranger III

108. The Mini-Ranger III is a line-of-sight positioning system manufactured by the Motorola Corp. A basic Mini-Ranger system consists of a mobile unit and two shore stations. Minimum components of the mobile unit include a transmitter/receiver (T/R), a range console, and a power source (Figure 56). Shore stations are set up at fixed and known locations. The master T/R interrogates the shore stations in turn and measures the elapsed time for the round-trip interrogation. Elapsed time from this measurement is effectively a measurement of distance since the velocity of electromagnetic energy through air is known. Interrogation of the shore stations is coded such that the responses are identified and displayed according to the selected channel. The standard Mini-Ranger system is capable of automatically interrogating any two of four possible codes.

109. Motorola specifications for the Mini-Ranger III are listed below:

- a. Operating frequency: 5400 to 5600 MHz.
- b. Range: 20 nautical miles (NM).
- c. Probable range error: ±3 m at 20 NM.
- d. Range readout units: metres, yards, or feet.
- e. Range display: two 5-digit ranges displayed simultaneously.
- f. Mobile unit antenna: omnidirectional azimuth; 250-deg elevation.
- g. Shore station antenna: 75-deg azimuth; 15-deg elevation.

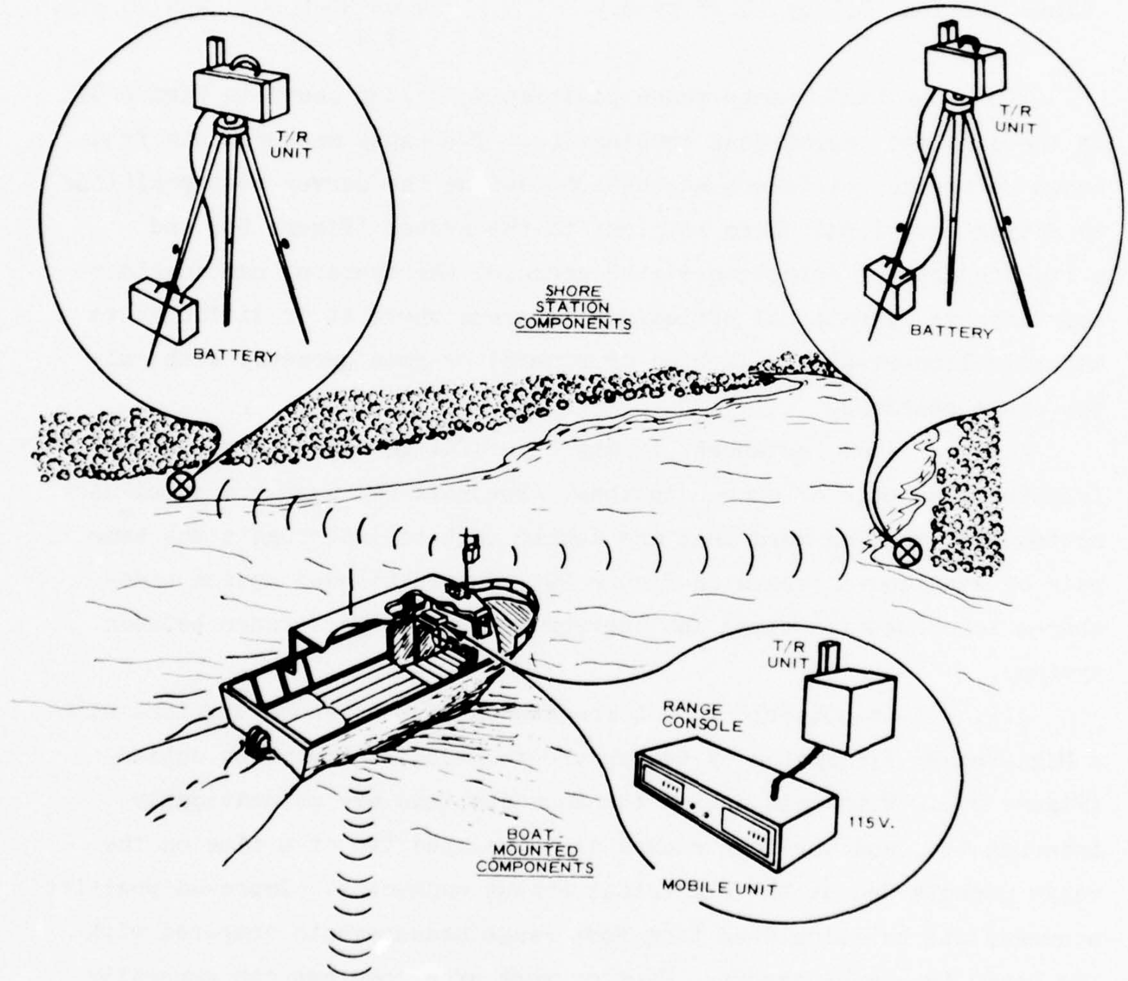

Figure 56. Components of basic Mini-Ranger III system

Component	Size, in.	Weight lb	Power	Temperature Range, °C
Range console	17 by 18 by 5.5	32 28	115 V/60 W 24 to 30-V DC	0 to 50
Transmitter/ Receiver	6.25 by 9.25 by 6.5	5	20 W	-40 to +60
Shore station	5.5 by 10.25 by 6.5	5	24 to 30-V DC, 13 W	-54 to +71

110. The basic range-range positioning system shown in Figure 57 is the simplest operational combination. Two range measurements from known reference points are adequate to define the survey boat position. By adding additional shore stations to the system (Figure 58) and switching channel selection at the console, the operator can considerably improve operational efficiency in areas where it is difficult to maintain line-of-sight (such as on rivers) or good geometry with only two shore stations.

111. In some instances, it may be useful to have two boats operate from the same pair of shore stations. Motorola can supply a multi-user option that enables more than one mobile unit to interrogate the same pair of stations as shown in Figure 59. The multi-user option time-shares interrogation times and thereby prevents interference between systems.

112. It is possible to interrogate up to four shore stations with a Mini-Ranger III system by adding the four-code commutation option (Figure 60). With this option the four stations are automatically interrogated, and the four ranges are displayed two at a time on the range console and at the electrical output connector. Improved position accuracy can be calculated from four range measurements compared with the basic two-range system. Greater work area coverage can generally be realized with the four-range system than with a two-range system because geometry is better and because the temporary loss of one, or perhaps even two range measurements, does not cause loss of position determination. The four-range system thus provides considerable improvement in operational problems associated with line-of-sight blockage due to obstructions and signal cancellation areas over water.

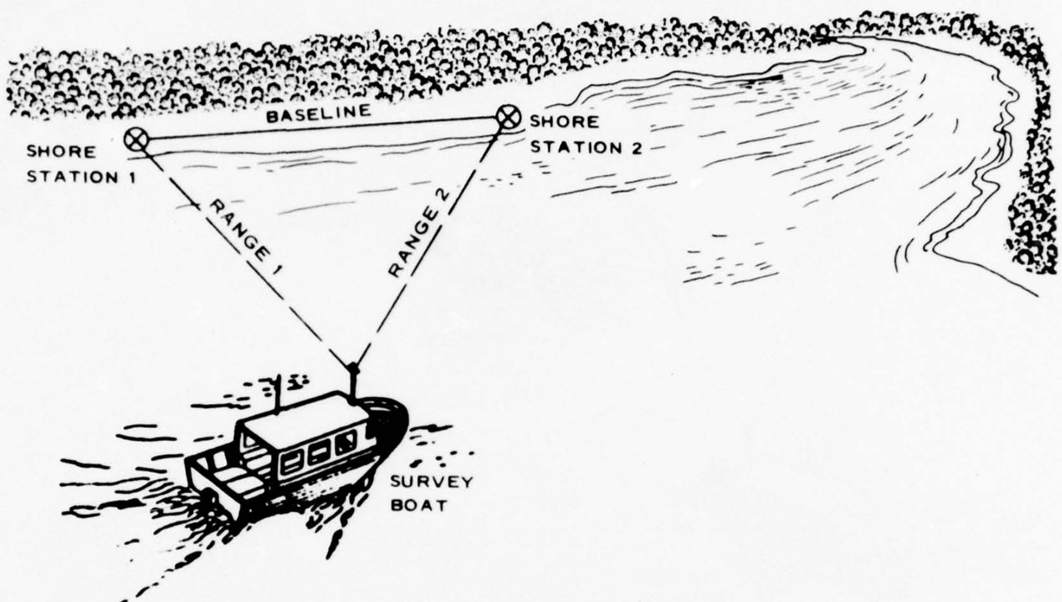

Figure 57. Operation of the basic Mini-Ranger III positioning system in the range-range mode

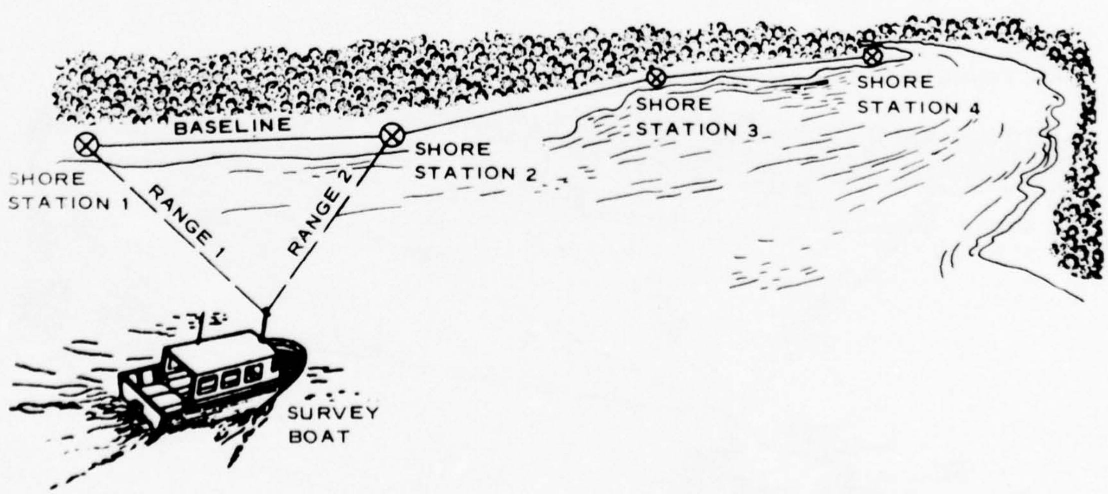

Figure 58. Capability of Mini-Ranger III to be switched to any two of four stations set up

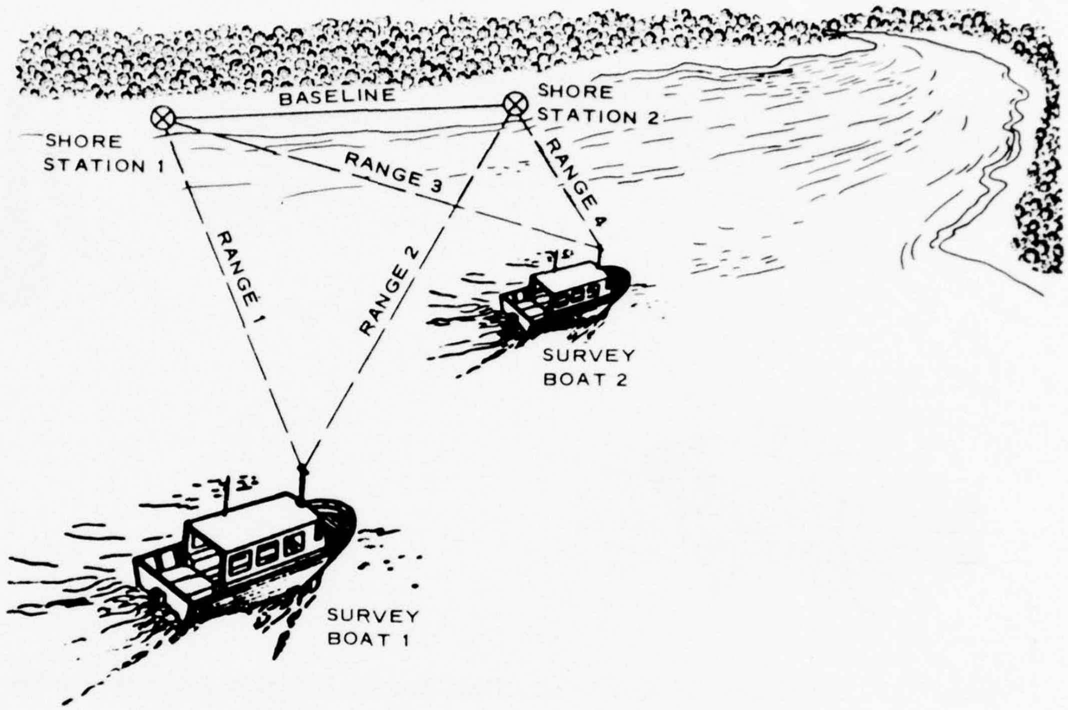

Figure 59. Mini-Ranger III system in range-range multiboat operation from two shore stations

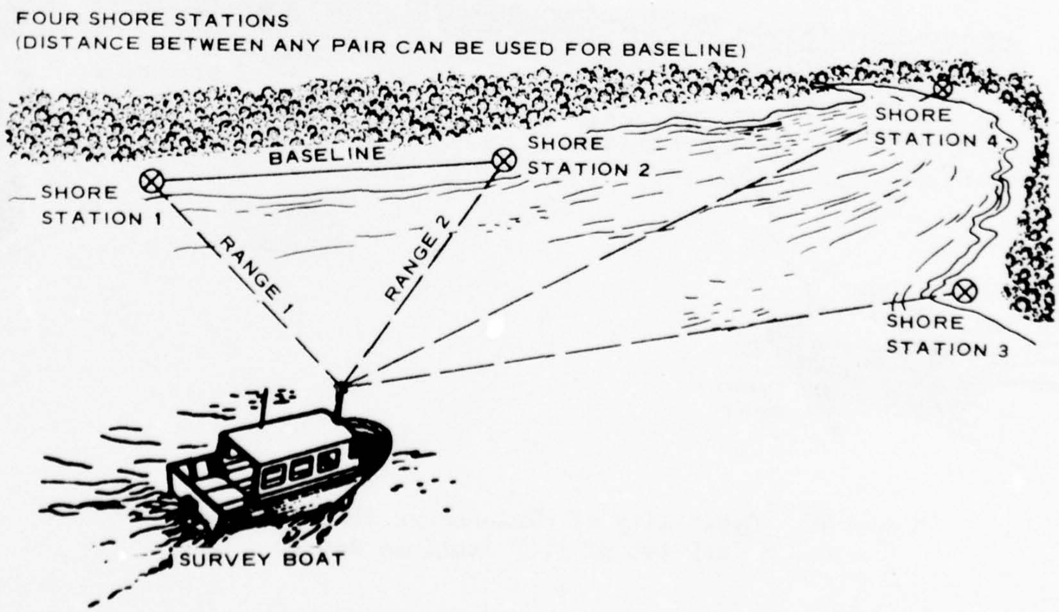

Figure 60. Mini-Ranger III system with four-code commutation option

Another multirange option adds the capability of interrogating up to 16 shore stations.

113. A common problem with all microwave DME operating over water is the loss of range information in certain areas due to signal cancellation effects (multipath). Motorola offers an option, the space diversity antenna, to greatly alleviate this problem. The space diversity option (Figure 61) consists of two vertically spaced T/R units coupled to an automatic switching unit that selects the stronger of the two T/R signals and sends this signal to the range console.

Options and auxiliaries

114. Other Mini-Ranger III distance-measuring-system (DMS) options about which the potential user might inquire include:

- a. Range averaging circuits.
- b. Optional antennas for greater range.
- c. Shore station standby option.
- d. Shore station backpack unit.
- e. Range mark increment option.
- f. Range-velocity console.
- g. Range-azimuth system.
- h. Remote range indicator or steering indicator.

Companion equipment

115. In addition to the basic Mini-Ranger positioning system, Motorola offers a large selection of companion units that can be combined in various ways to make up a complete set of electronic hydrographic survey instruments adapted to a specific project. Listing these in order of increasing sophistication, the Motorola companion equipment can be used to assemble the following types of systems: (a) portable data logger, (b) fixed installation data logger, (c) microprocessor-controlled system, (d) calculator-controlled system, and (e) minicomputer-controlled system.

116. Portable data logger. For small-boat application, Motorola offers a portable data logger that, combined with the Mini-Ranger III, provides a complete hydrographic survey data acquisition system. This

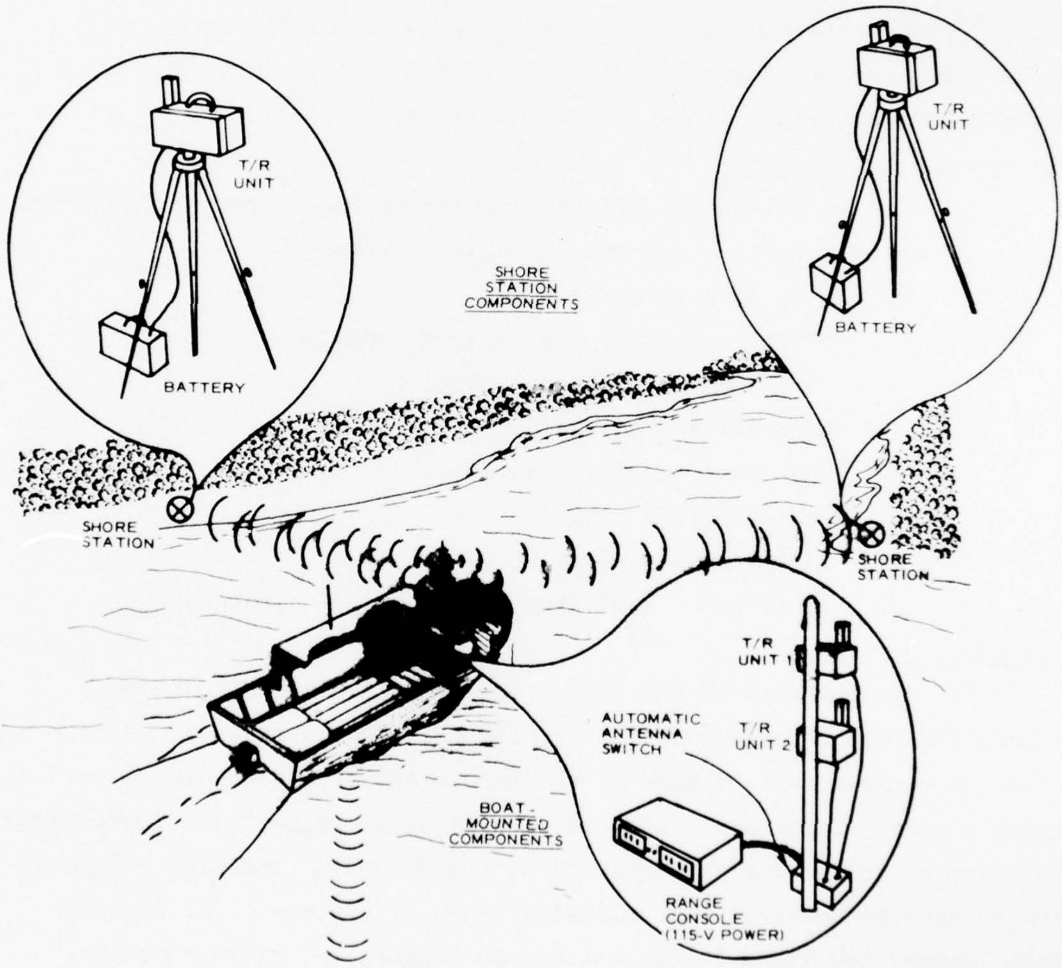

Figure 61. Components of Mini-Ranger III system with multipath compensation option

data logger performs the functions illustrated in Figure 62 and includes the functions of:

a. Digital depth sounder.

b. Time-of-day clock.

c. Manual entry and control panel.

d. Cassette recorder.

e. Cassette reader.

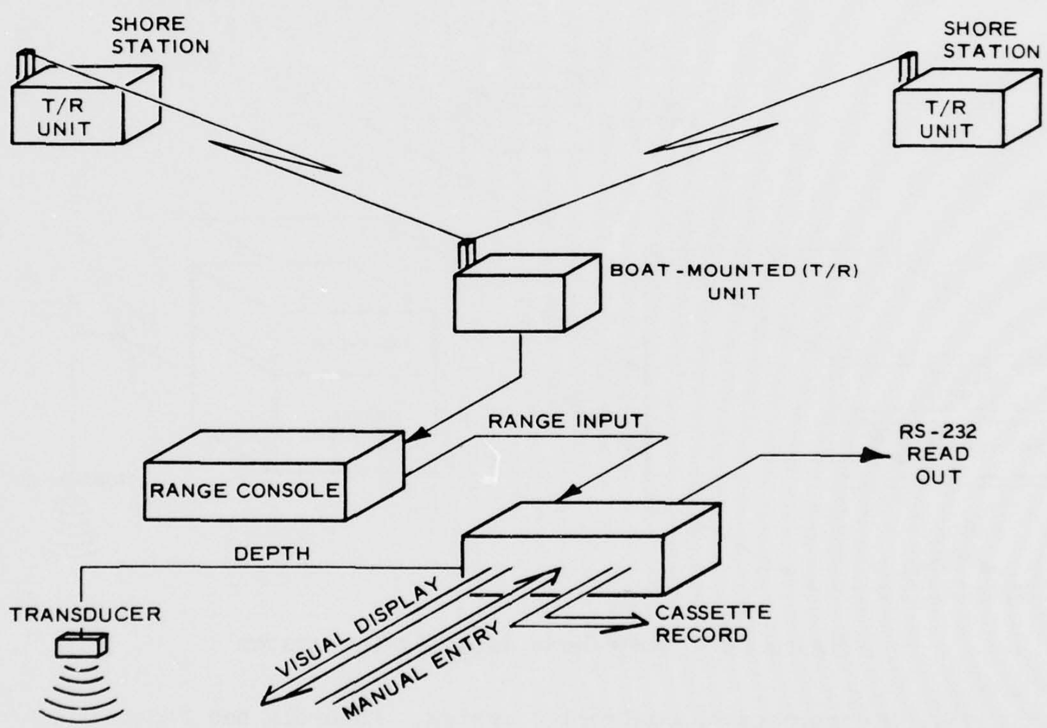

Figure 62. Motorola portable data logger

117. Physical design specifications for the portable data logger are listed below:

a. Housing: watertight aluminum case.

b. Housing size: 12 by 17 by 18 in.

c. Housing weight: less than 40 lb.

d. Power: 12-V DC.

118. Fixed installation data logger. Motorola will supply a larger data logging system that can perform the functions shown in

Figure 63. This is a large unit intended for permanent installation in a survey boat. The big difference between this unit and the portable data logger is that the larger unit generates computer compatible tape on a reel-type magnetic-tape recorder.

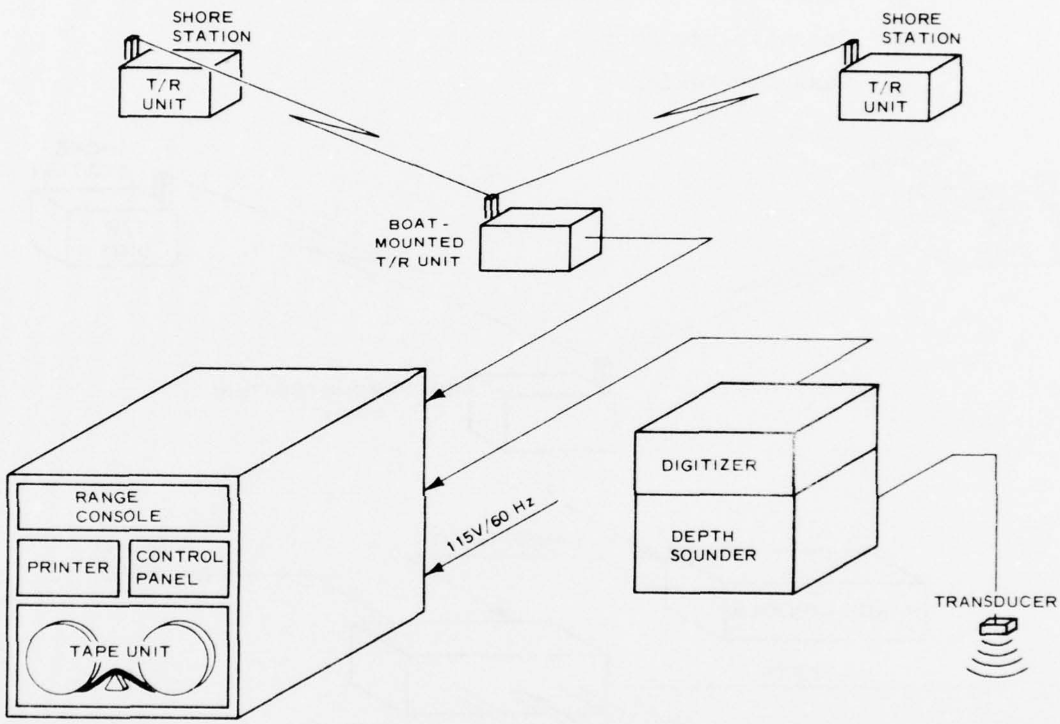

Figure 63. Large-boat data logging system

119. Microprocessor-controlled system. Motorola has recently introduced a microcomputer-based data processor for use in hydrographic survey systems. The Mini-Ranger Data Processor System is smaller and less expensive than a minicomputer system but somewhat less versatile. It is perhaps an intermediate system between a calculator-based system and a minicomputer-based system. The Mini-Ranger Data Processor System may include: (a) track plotter, (b) steering indicator, and (c) printer.

120. Calculator-controlled system. As an intermediate size survey system, Motorola offers a calculator-controlled system. Calculator processing of the range data permits boat guidance functions to be performed as well as data collection. This system operates slower than the

minicomputer-controlled system but has a cost advantage. The calculator can also be readily used for other purposes when not needed for survey work. The calculator-controlled system can include: (a) track plotter, (b) steering indicator, and (c) printer.

121. Minicomputer-controlled system. Motorola can supply a minicomputer-controlled survey system to meet very sophisticated survey needs. The Motorola Automatic Survey System provides the capability of steering preselected straight lines in arbitrarily selected coordinate systems. In addition, the system can record survey data while proceeding on course. A permanent record of boat track is provided by an onboard plotter, while the survey data is recorded on magnetic tape in computer compatible form.

Del Norte/Trisponder

122. The Del Norte Technology Corp. offers a line of microwave positioning systems under the trade name Trisponder. A basic Trisponder positioning system consists of a mobile unit and two shore stations. Minimum components of the mobile unit include a transmitter/receiver (T/R) with omnidirectional antenna, a range display unit, and a power source of 24-V DC (Figure 64). Shore stations are set up at fixed and known locations with line-of-sight coverage of the survey area. The master T/R interrogates the shore stations in turn and measures the elapsed time for the round-trip interrogation. Elapsed time from this measurement is effectively a measurement of distance since the velocity of electromagnetic energy through air is known. The interrogation rate is many times per second so that position error due to measurement lag is minimized. Interrogation of the shore stations is coded such that the responses are identified and displayed according to the selected channel. The standard Trisponder system is capable of automatically interrogating any two of four shore station codes. Del Norte manufactures several different Trisponder positioning systems, and the differences between models are large enough that the different models will be discussed separately.

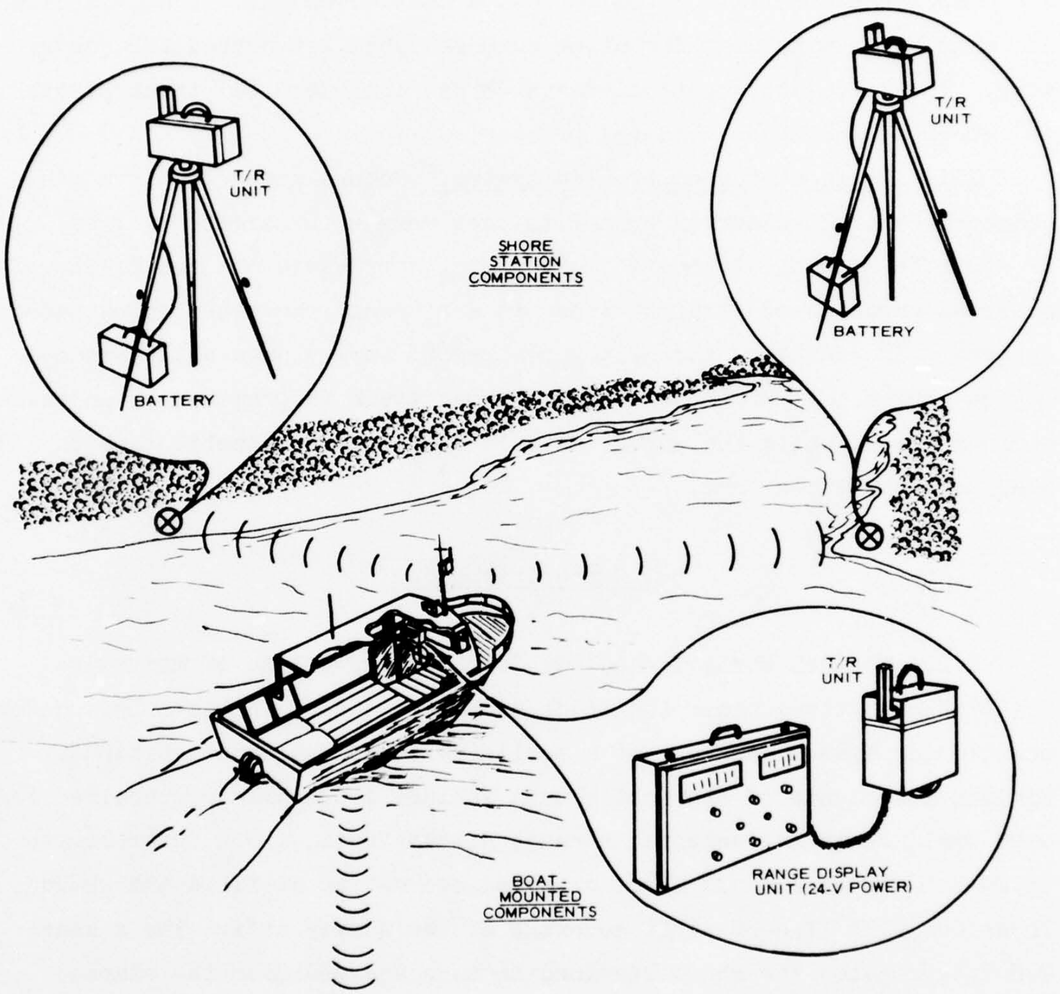

Figure 64. Components of basic Trisponder range-range positioning system

Specifications

123. Del Norte specifications for a standard Model 202 Trisponder survey system are as follows:

a. Operating frequency: 9200 to 9500 MHz.

b. Range: 50 miles.

c. Accuracy: ±3 m.

d. Resolution: 0.5 m (100-sum mode) or 1 ft optional.

e. Range display: two 5-digit ranges displayed simultaneously.

f. Mobile unit antenna: omnidirectional azimuth; 30-deg elevation.

g. Reference station antennas: 87-deg azimuth; 5-deg elevation.

Component	Size, in.	Weight lb	Power	Temperature Range, °C
DMU*	13.5 by 16 by 11	25	23 to 32-V DC, 2.4 A	0 to 67
Transponder	14 by 6 by 10.5	15	23 to 32-V DC, 0.8 A	-30 to +70

* Distance-measuring unit.

Switchable shore stations

124. The basic range-range positioning system shown in Figure 65 is the simplest operational combination and lowest in initial cost but not always the lowest in operational costs. With additional transponder units at selected shore locations, the operator can considerably improve

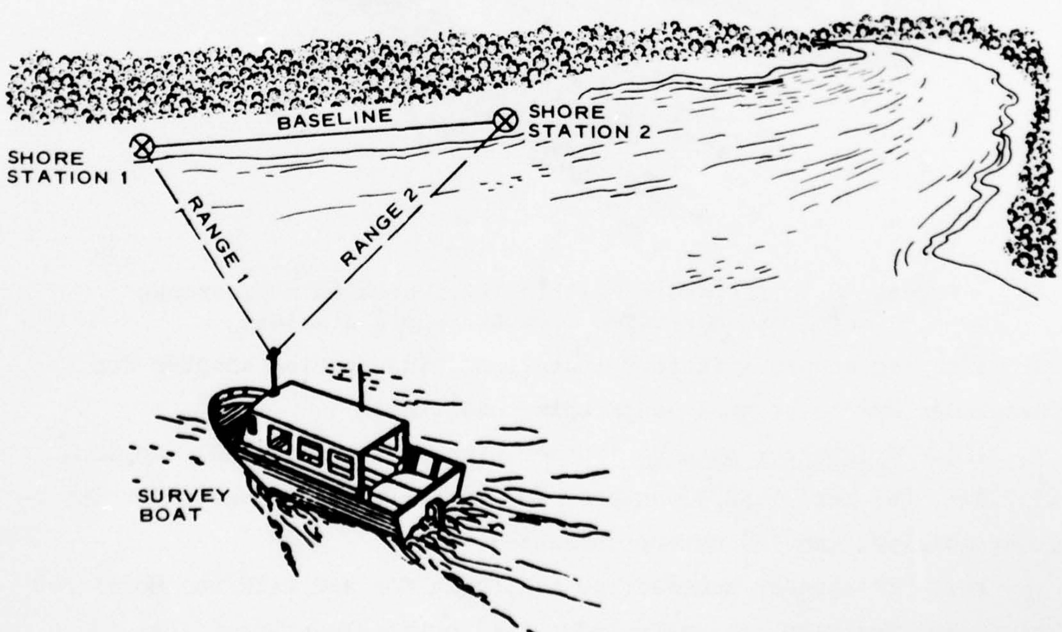

Figure 65. Operation of the basic Trisponder positioning system in the range-range mode

operational efficiency in areas where it is difficult to maintain line-of-sight to a pair of shore stations (such as on rivers). In some areas, there may be no obstruction to line-of-sight, but the geometry of position determination can be improved by having alternate shore stations. The standard DMU permits the operator to select any two of four coded transponder units to obtain the best operational condition.

125. Multiboat operation. In some instances, it may be useful to have two boats operate from the same pair of shore stations (Figure 66).

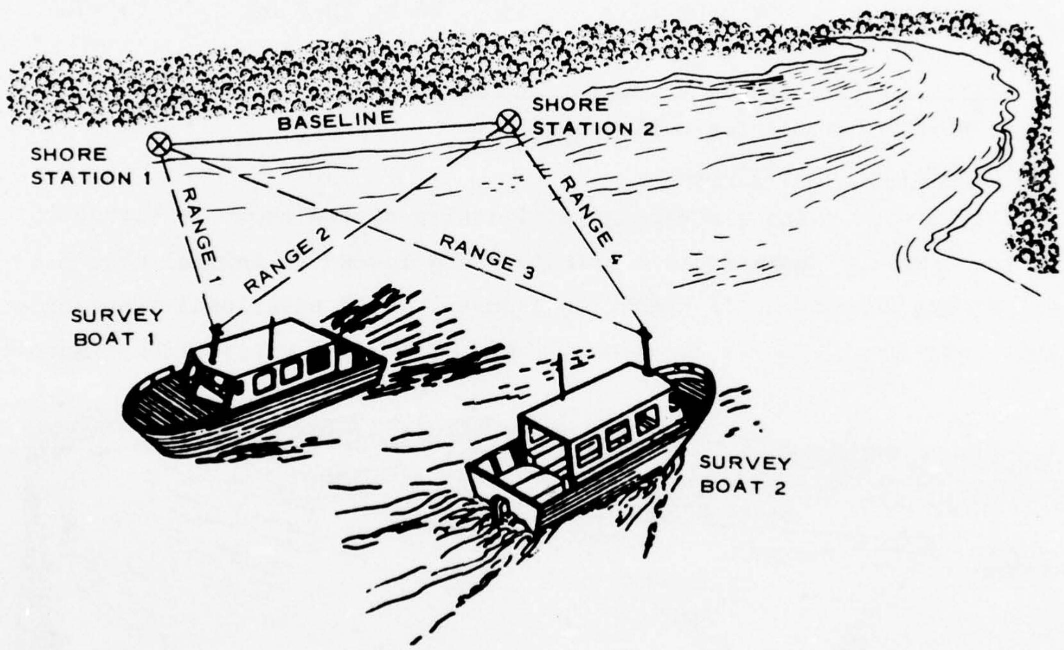

Figure 66. Trisponder positioning system in range-range multiboat operation from two shore stations

Del Norte can supply a factory-installed, time-sharing adapter for Trisponder DMU to be used under this condition.

126. Trisponder options. Other significant Trisponder options include: (a) serial ASCII output, (b) master/remote transponder interchangeability, and (c) waterproof cases.

127. Trisponder accessories available for use with the Model 202 Trisponder position system include: (a) optional antennas, (b) arc steering indicator, (c) remote display, and (d) serial ASCII output. Also available are several good maintenance accessories, such as radio

frequency (RF) detector for T/R unit checks, field link simulator, and system spares kit.

128. Solid-state Trisponder. A new transponder model has recently been introduced by Del Norte. The Model 260 transponder is a small, light-weight, low-power unit that should be very useful in small boats operating primarily in rivers. The Model 260 unit contains a rechargeable battery with capacity to operate the unit for 10 hr. This unit should be particularly convenient and useful where frequent changes of shore stations are necessary. The main compromise between this unit and the Model 202 is the reduced range. Specifications for this unit are summarized below:

- a. Operating frequency: 9200 to 9500 MHz.
- b. Range: 5 km.
- c. Accuracy: ±1 m.
- d. Resolution: same as 202A.
- e. Range display: same as 202A.
- f. Voltage: 12-V DC (11.5- to 30-V DC).
- g. Power: 5.5 W at 12-V DC.
- h. Battery pack: 10 hr, rechargeable.
- i. Master transponder weight: 8.5 lb.
- j. Remote transponder weight: 15.5 lb (total) including battery pack.
- k. Master transponder size: 9.3" by 4.4" by 8.4".
- l. Remote transponder size: 13.8" by 4.4" by 8.4" including battery pack.

129. Eight-channel DMU. For some applications, the use of more than two shore stations can be of considerable advantage in improving operational efficiency. Position determined from more than two ranges will have a significantly improved accuracy because of improved geometry. A second advantage is that the loss of one range measurement out of three or more does not cause the loss of boat position as would result when one range measurement is lost out of a two-range system. This situation is a common problem with all microwave DME operating over water where one channel of range information may be lost in certain

areas due to signal cancellation effects. Using more than two shore stations can alleviate the problem. Del Norte markets a multichannel DMU that measures ranges to eight shore stations. Any two ranges out of the eight can be displayed. All eight ranges are available at the electrical output connector. The multichannel DMU also relieves the operator of the need to select channels when moving from one station area to another. Figure 67 is a sketch of the multichannel DMU operation.

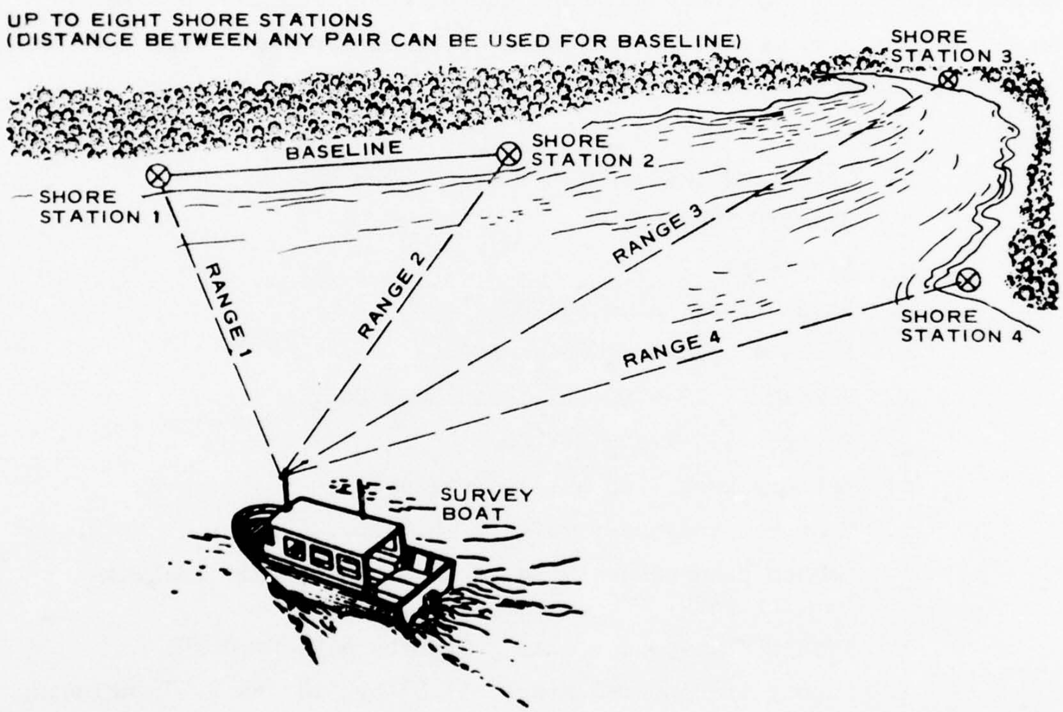

Figure 67. Trisponder positioning system with multichannel DMU option

130. Del Norte also manufactures another model, a multichannel tracking station with the trade name Multi-Tracker. This system is designed for tracking up to 30 transponders. Two Model 250 tracking stations located at fixed positions can thus track a large number of moving targets. Accuracy is equivalent to the other Trisponder systems. One innovation with this system is the use of serial ASCII control and data signals. This will facilitate interfacing the Model 250 with remotely located computers or other automatic data acquisition systems.

Cubic/Autotape

131. The Cubic Industrial Corp. offers a microwave DMS under the trade name Autotape. A basic range-range system consists of the mobile unit and two shore stations. Distance between the mobile unit and each of the shore stations is derived by measuring the round-trip transit time of an electrical signal that is sent from the master unit and returned by the shore unit. An Autotape DMS measures transit time by a phase-comparison method in contrast to the pulse-arrival method used in the Mini-Ranger and Trisponder.

132. Autotape specifications are as follows:

a. Operating frequency: 3 GHz approximately.

b. Range: line-of-sight (up to 100 km).

c. Accuracy: ±1 m.

d. Resolution: ±0.1 m.

e. Range display: two 5-digit ranges displayed simultaneously.

f. Mobile antenna: omnidirectional azimuth, 10-deg vertical.

g. Shore antenna: variable azimuth.

h. Temperature range: -10 to +50°C.

i. Mobile unit power: 100 W at 12-V DC.

j. Shore unit power: 75 W at 12-V DC.

133. A basic range-range positioning system for an Autotape-equipped boat is illustrated in Figure 68. Variable beam shore station antennas, a unique feature of Autotape systems, allow the user to optimize beam width for a specific site. Figure 69 shows the geometry of a basic range-range positioning system. Cubic also manufactures a three-range system (Figure 70) that can give better positioning accuracy than a two-range system for a given distance measurement accuracy. A three-range system also reduces the probability of suspended operations when encountering dead zones (multipath) in an operating area. If one range measurement is blocked by obstructions or interfacing reflections, the remaining two range measurements are enough to define position.

134. Autotape systems constitute the largest number of any one

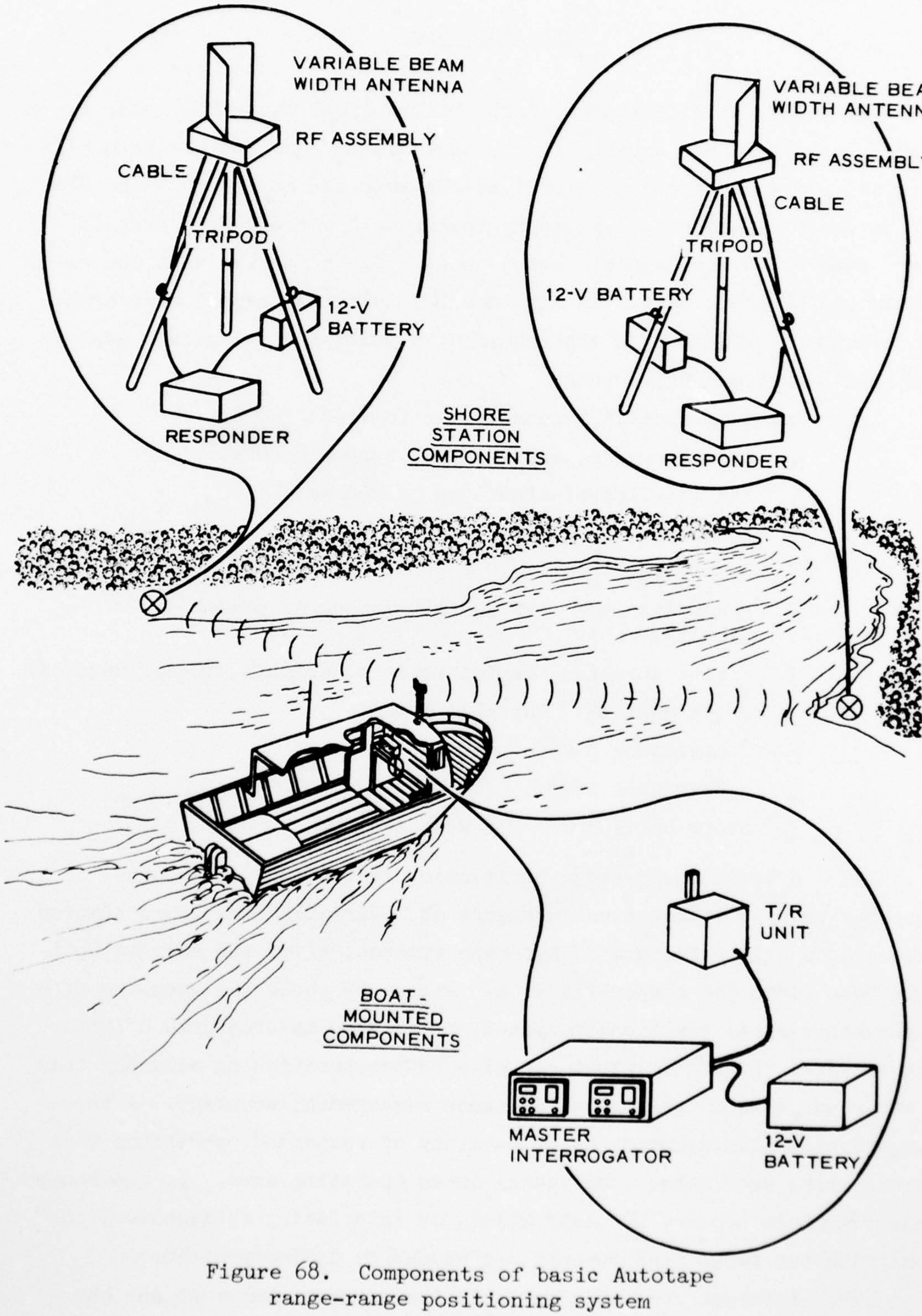

Figure 68. Components of basic Autotape range-range positioning system

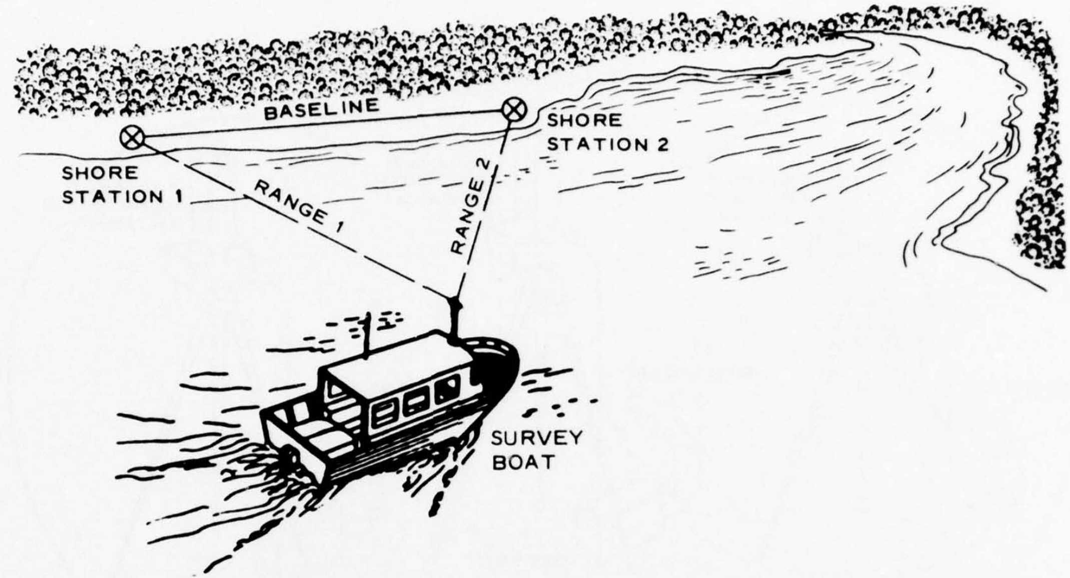

Figure 69. Operation of the basic Autotape positioning system in the range-range mode

type of positioning system in use by the Corps. The majority of Corps users have expressed satisfaction with the performance and reliability of the equipment. When maintenance was needed, the response from Cubic has been very good. For large survey boat operations, an Autotape system justifies its high cost by providing reduced downtime and high accuracy as compared with lower cost systems.

Plessy/Tellurometer

Tellurometer/MRB 201

135. The Tellurometer Division of Plessy Electronics Corp. manufactures a dynamic positioning system designated by Model MRB201. The basic MRB201 is a single-range unit designed to measure distance from a fixed shore station to a moving vessel. To measure the position of a moving boat, two MRB201 units are used to measure distances to two established shore stations (range-range mode). As an alternate, one MRB201 can be operated in conjunction with a manually sighted transit to obtain range-azimuth positioning information. For range-range operation, Tellurometer will package two master units in one case for ease

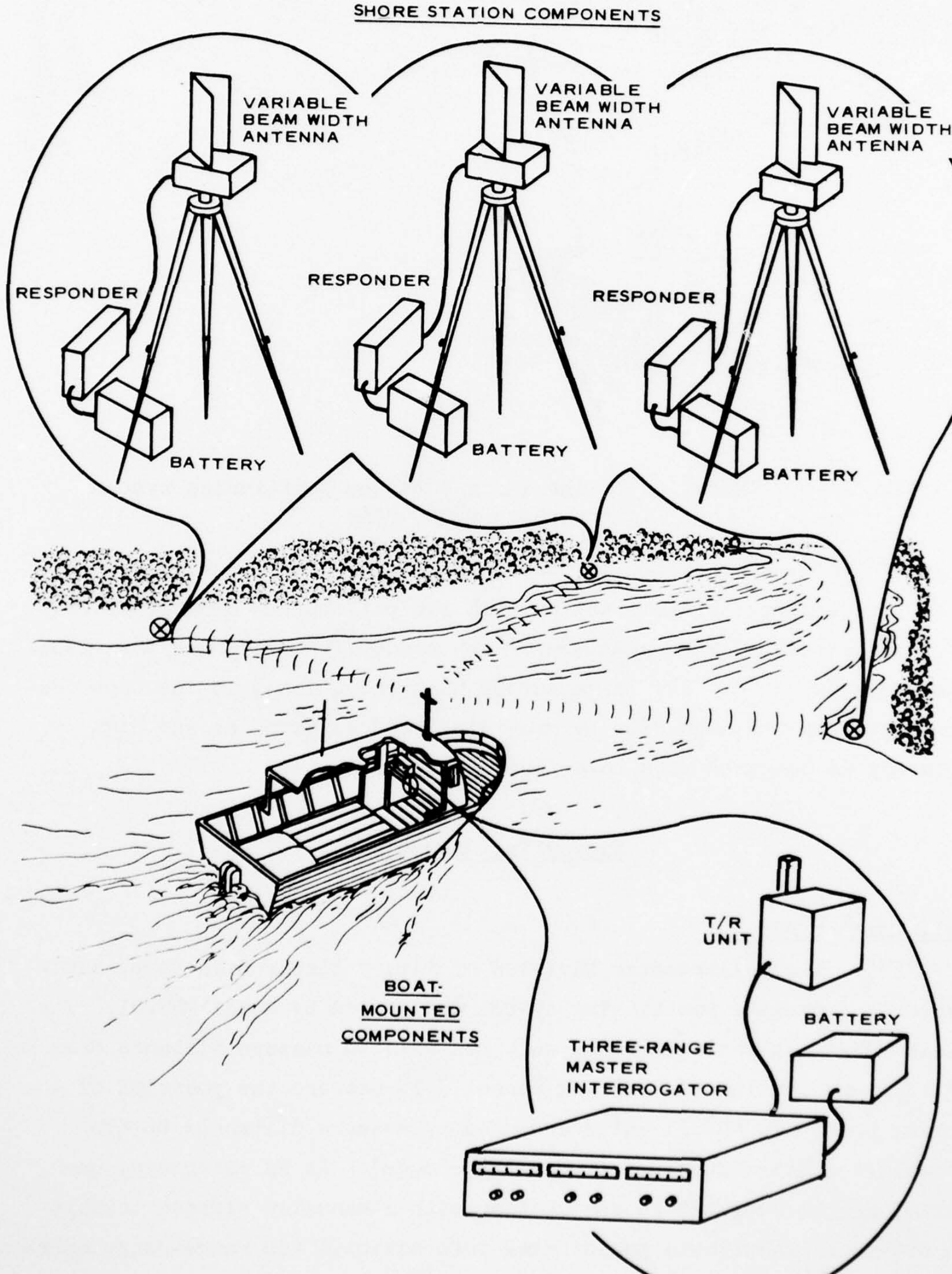

Figure 70. Components of three-range Autotape positioning system

of shipboard handling. Figure 71 illustrates a basic two-range system.

136. Model MRB201 operates in the 3-GHz frequency band and uses phase comparison as a distance determining technique. Tellurometer will supply different types of antennas to optimize operating characteristics.

137. The specifications for this model are as follows:

a. Operating frequency: 2800 to 3200 MHz.

b. Range: 10 km with omnidirectional antenna; 250 km with 24-in. circular reflector.

c. Accuracy: static -- ±0.5 m (±3 by 10^{-6} distance); dynamic -- ±1.5 m.

d. Resolution: 0.1 m.

e. Range display: 5-digit.

Tellurometer/CA-1000D

138. Tellurometer has recently introduced a modified version of their CA-1000 surveying instrument with a dynamic measurement capability. The standard CA-1000 is a small, lightweight, static surveying instrument designed for precise land surveying. Since it is a microwave instrument, haze and fog do not limit its use as would be the case with optical instruments.

139. The CA-1000D has a dynamic mode section that allows an operator to track a moving vessel with an accuracy of ±2 ft at ranges up to 15 miles. The distance the boat moves is continously presented in feet on a single-range digital display. The output is available in electrical form for interface with data loggers, etc. The CA-1000D uses a wavelength counting technique for the dynamic distance measurement. If the beam is interrupted, the totalized count is lost. The operator must, therefore, guide the boat to maintain line-of-sight, and the boat personnel must be trained to avoid walking between the boat antenna and the shore responder.

140. The low cost of this instrument, compared with other electronic DME, makes this unit an economic solution for small boats operating on fixed ranges.

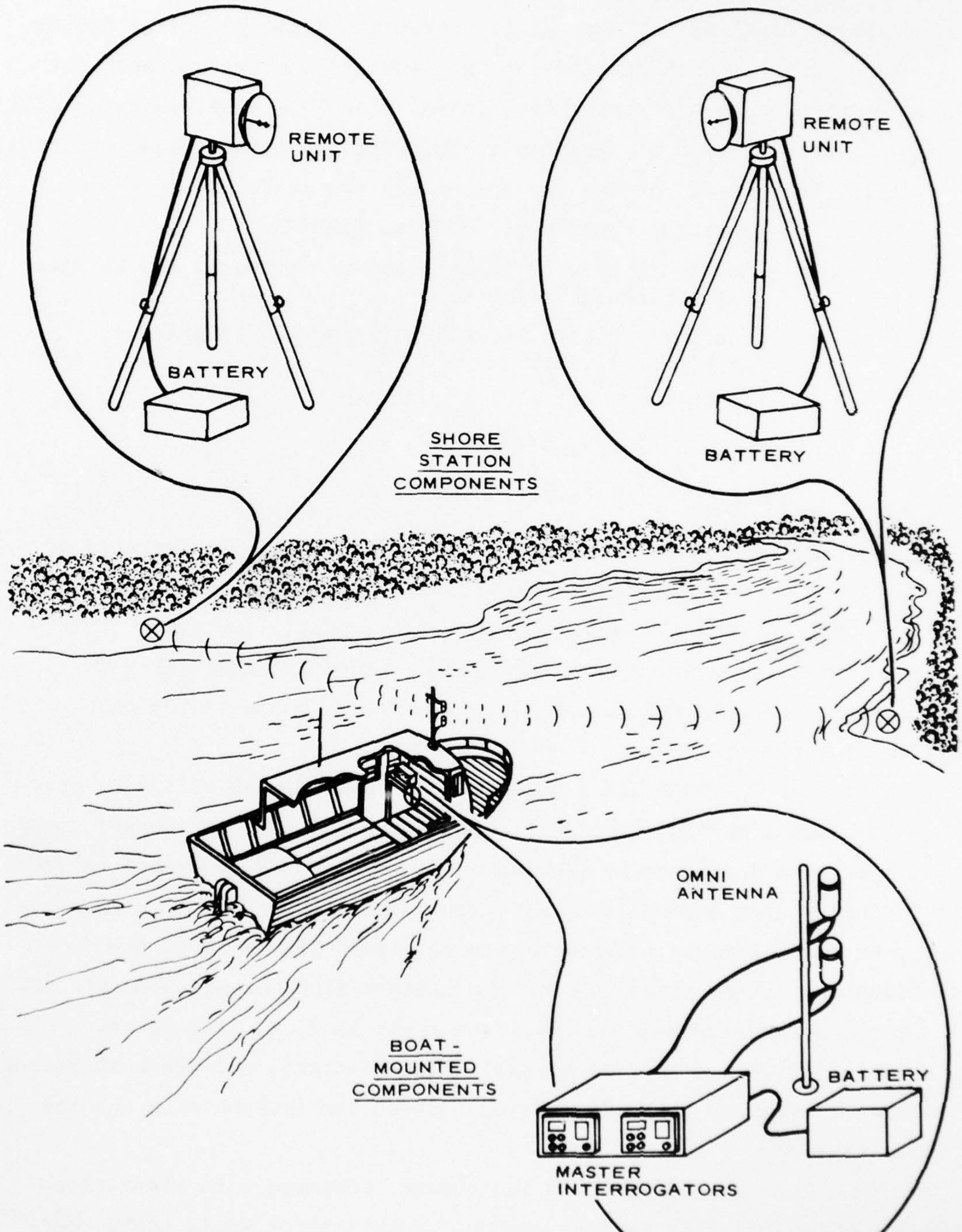

Figure 71. Components of Tellurometer range-range positioning system

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POSITIONING TECHNIQUES AND EQUIPMENT FOR U.S. ARMY CORPS OF ENG--ETC(U)
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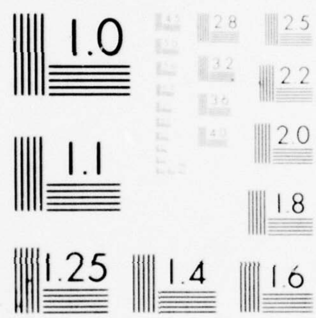

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Navigation Management/Maxiran and Miniran

Maxiran

141. Navigation Management, Inc., has recently decided to market their Maxiran positioning system to the Government in addition to proprietary sales to Offshore Navigation, Inc. This positioning system operates in the 420- to 450-MHz band that is intermediate between the microwave systems such as Trisponder and the radio frequency (RF) systems such as Raydist. Therefore, this operating frequency gives transmission characteristics intermediate between the microwave and RF systems characteristics. The Maxiran system can operate at ranges up to 300 miles over sea paths, comparable with the range capability of RF systems. As another plus factor, this type system will have signal cancellation zones spaced wider apart than microwave systems. However, the range is limited overland to line-of-sight due to signal attenuation by vegetation. The French-made positioning system marketed under the trade name Syledis is probably the most similar commercially available equipment.

142. The Maxiran system is designed to operate with three shore stations for improved accuracy but can be operated with only two if desired. Figure 72 illustrates the three-range operation of this system. The mobile unit console displays the three measured ranges to the operator plus date, time, and event count. This information is also available at rear connectors in both parallel and serial form for interface with associated equipment, such as data loggers and boat guidance systems.

143. The principle of operation of a Maxiran system is very similar to that of a Trisponder or Mini-Ranger system. A master T/R interrogates the shore stations in turn and measures the elapsed time for the round-trip interrogation. From the elapsed time measurement, the distance can be computed and provided as an output from the instrument. This measurement technique does not involve the possibility of lone-count loss as exists with most of the nonline-of-sight systems.

144. A Maxiran system can be operated with six shore stations,

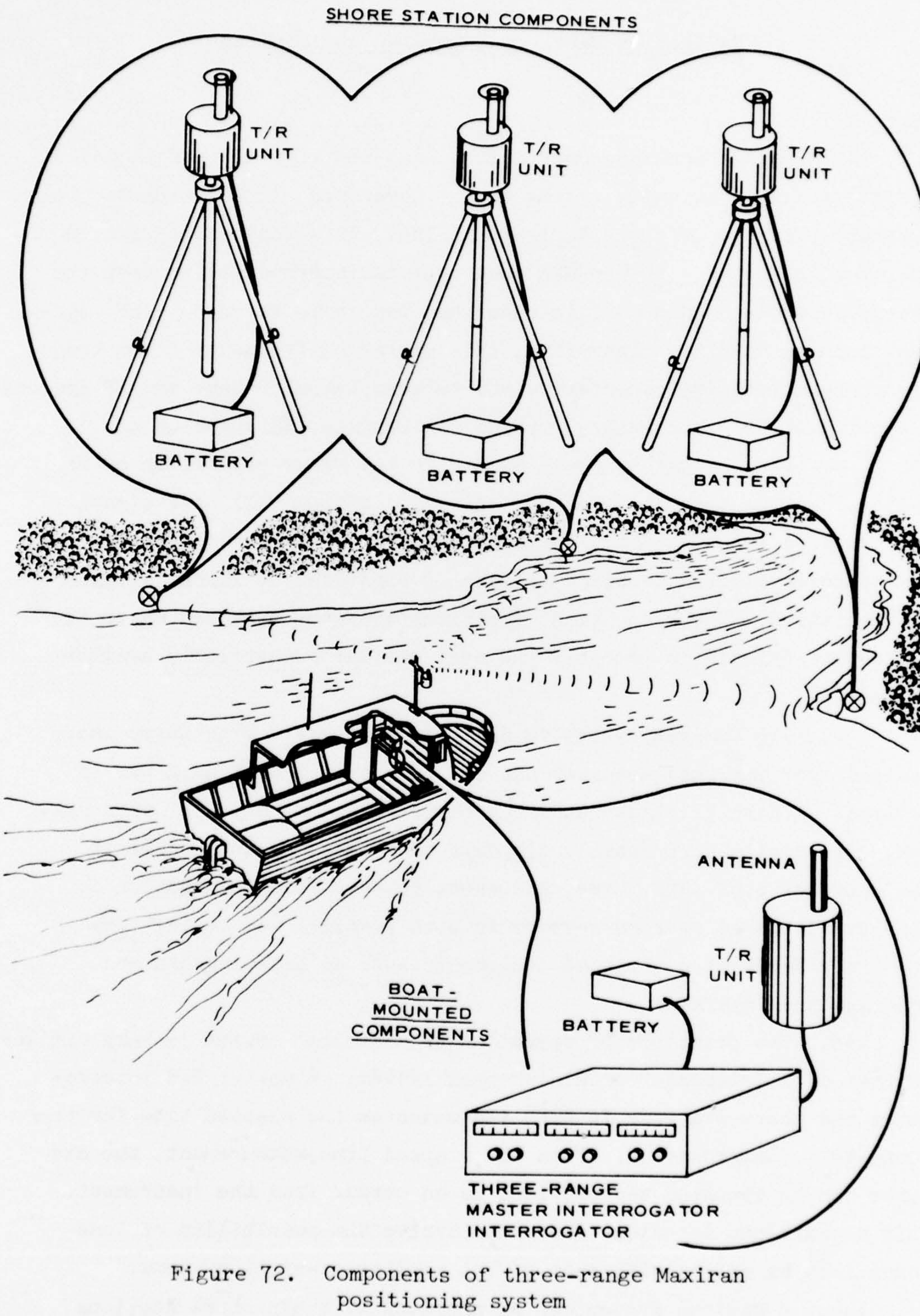

Figure 72. Components of three-range Maxiran positioning system

with the operator being able to select any three of the six stations for interrogation. This feature enables the operator to maintain good geometry over an area that cannot be adequately covered by two or three shore stations.

145. Several options are available with the Maxiran system. Linear power amplifiers for the transmitters extends the range from 150 to 300 miles (with antennas at sea level). High-gain antennas can extend the range up to 400 miles. The console of this system can be used with Miniran T/R stations if desired.

146. The Maxiran system has the following specifications:

a. Operating frequency: 420 to 450 MHz.

b. Range: standard--150 miles; optional power--300 miles.

c. Accuracy: ±3 m.

d. Range display: 3 ranges displayed simultaneously.

e. Resolution: 1 m.

f. Mobile unit antenna: omnidirectional azimuth.

g. Shore station antennas: 180-deg azimuth.

h. Power: shore stations--12-V DC; mobile stations--115 V/16 Hz.

Miniran

147. Navigation Management, Inc., offers a microwave positioning system under the trade name Miniran that is competitive with Trisponder and Mini-Ranger, with lower cost being a key marketing factor. A basic Miniran system consists of a mobile unit and two shore stations (Figure 73). The operating frequency is approximately 3 GHz so the signal transmission characteristics will be similar to Autotape or Tellurometer (line-of-sight only). Distance measurement, however, is based on pulse transit-time techniques similar to Trisponder and Mini-Ranger.

148. For a typical operation, shore stations are set up at fixed and known shore locations with line-of-sight coverage of the survey area. The master T/R interrogates the stations in turn, and the elapsed time for the round-trip interrogation is measured. Distance is computed from this measurement based on the velocity of electromagnetic energy through air.

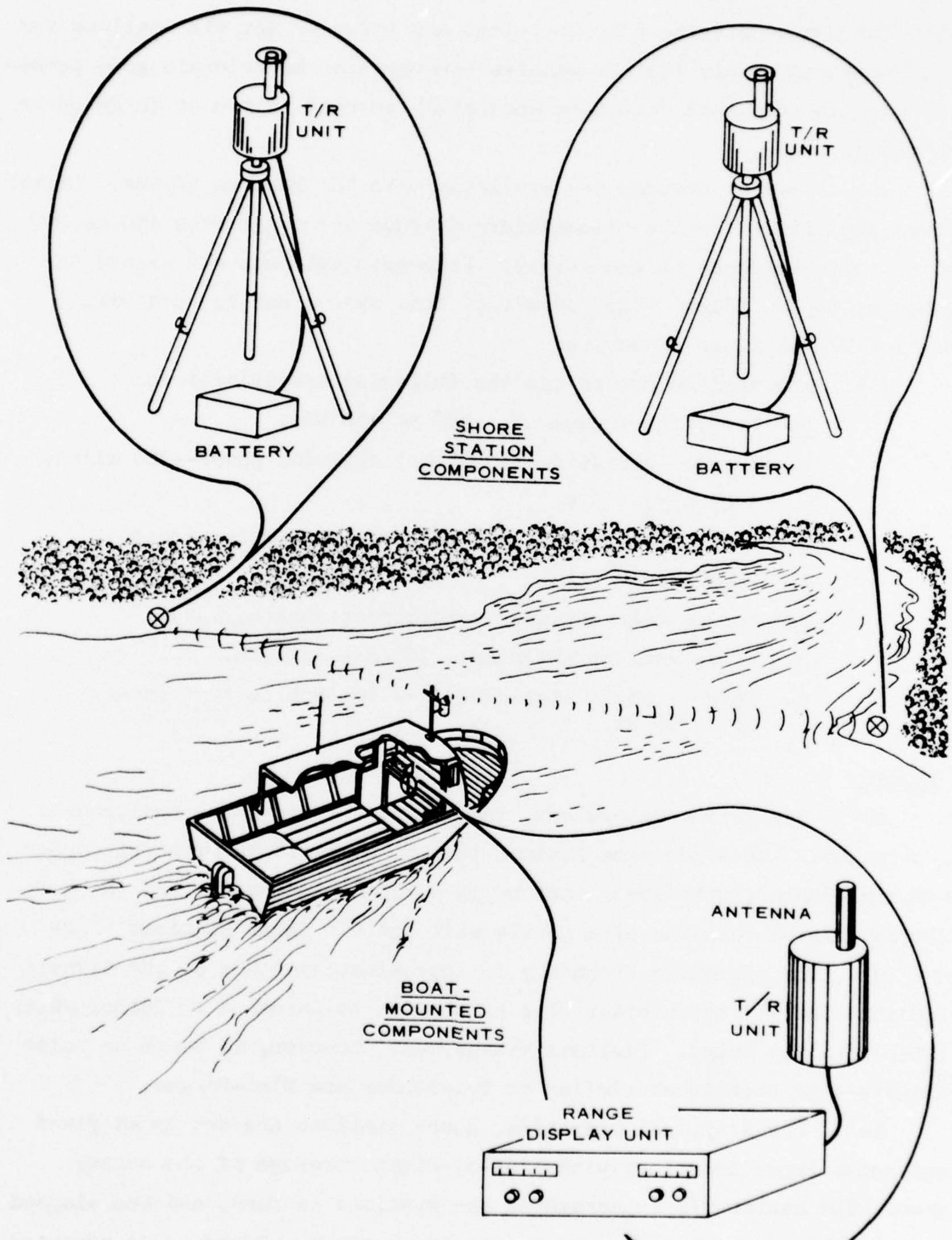

Figure 73. Components of Miniran range-range positioning system

149. The electrical output of the Miniran system is suitable for interface with data loggers and boat guidance systems. The mobile station operator can select any two of up to six shore stations to maintain good geometry.

150. The Miniran system has the following specifications:

<u>a</u>. Operating frequency: 2900 to 3100 MHz.

<u>b</u>. Range (standard antennas): 30 miles.

<u>c</u>. Accuracy: ±2 m.

<u>d</u>. Range display: two ranges displayed simultaneously.

<u>e</u>. Resolution: 1 m.

<u>f</u>. Mobile unit antenna: omnidirectional azimuth.

<u>g</u>. Shore station antennas: 120-deg azimuth.

<u>h</u>. Power: shore--12-V DC at 2 A/transmit, 0.5 A/standby; mobile--12 V or 115 V/60 Hz.

<u>i</u>. Weight: shore--12 lb; mobile--45 lb.

Sercel/Syledis and Toran

Syledis

151. Sercel, a French corporation, manufactures a positioning system operating in the 420- to 450-MHz band under the trade name Syledis. This system has a number of unusual characteristics to set it apart from other electronic DME. The operating frequency gives transmission characteristics intermediate between microwave DME such as Trisponder and low-frequency systems such as Raydist.

152. In addition to operating frequency, Syledis is unusual in its use of a recently developed signal-processing technique that considerably enhances the range and accuracy of this system compared with systems using more conventional techniques. The correlation method of signal processing used by Syledis allows the pulse modulation energy to be spread over a long pulse, while it maintains the accuracy of transit-time determination normally associated with extremely short pulses. A Syledis pulse of 2.6-msec duration is equivalent to a 0.5-msec pulse using conventional detection methods. The long-pulse width reduces

bandwidth and peak power requirements compared with short-pulse techniques. A wide bandwidth forces the designer to choose a microwave operating frequency with attendant inherent compromises in signal attenuation and multipath interference. The 420- to 450-MHz operating frequency allows the designer more options in signal amplification for pulse transmission and makes it possible to achieve considerably greater range than microwave systems with equivalent antenna heights. The manufacturer claims operating ranges up to three times line-of-sight using booster amplifiers with the transmitters. Manufacturer's representatives have also verbally expressed confidence in working through a limited amount of such vegetation as may occur in river bends or marshlands where optical or microwave line-of-sight may be blocked.

153. The Syledis system can be operated in a number of modes. In the range mode, a system can be configured for either two- or three-range operation. In the two-range configuration, up to nine mobile units can work simultaneously from two shore stations (Figure 74). In the three-range configuration, up to seven mobile units can work simultaneously from three shore stations (Figure 75). In both the two- and three-range configurations, the working shore stations can be selected from among eight coded responders. Figure 76 illustrates the components of a basic system consisting of a single mobile unit and two shore stations.

154. In the hyperbolic mode, any number of mobile units can operate from a selected pair of shore stations.

155. In the compound mode, up to five mobile units can work simultaneously from three shore stations, while at the same time an unlimited number of mobile units can work in the hyperbolic mode (Figure 77).

156. Specifications for a Syledis system are as follows:

- a. Operating frequency: 420 to 450 MHz.
- b. Range (standard antenna): twice line-of-sight over water.
- c. Range with high-gain antenna and booster amplifier: 3.5 times line-of-sight over water.
- d. Distance accuracy: ±1 ft at ranges within line-of-sight; ±10 ft at maximum range.
- e. Weight: interrogator--33 lb; beacon--33 lb; booster amp--55 lb.

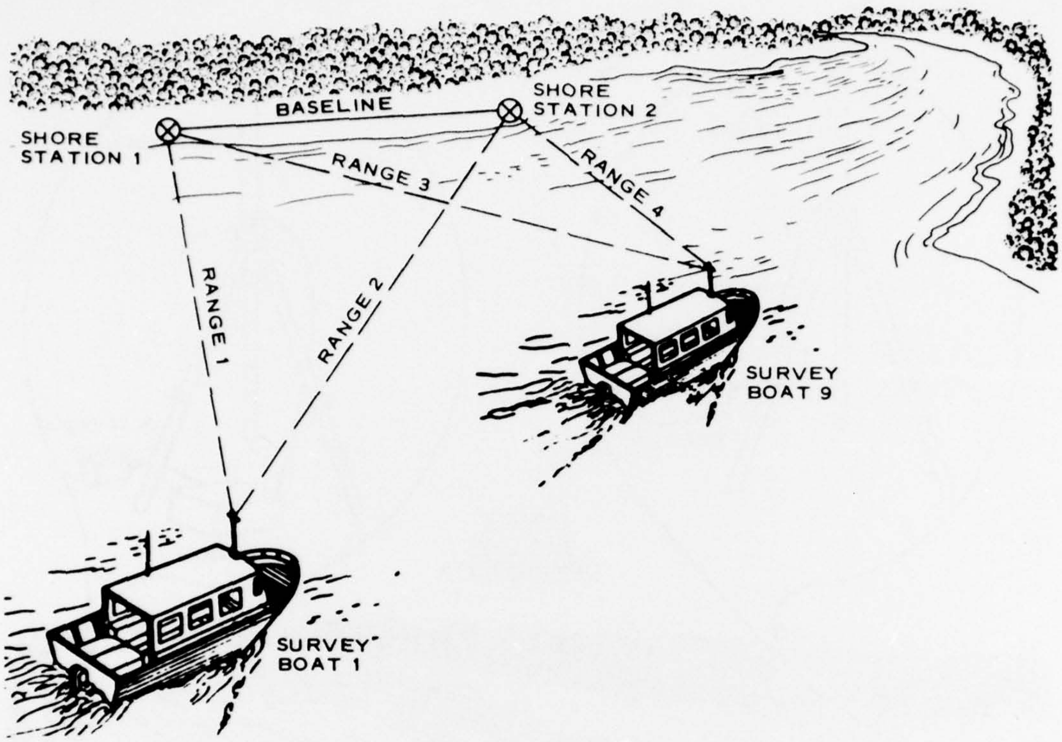

Figure 74. Two-range configuration of Syledis positioning system working up to nine survey boats

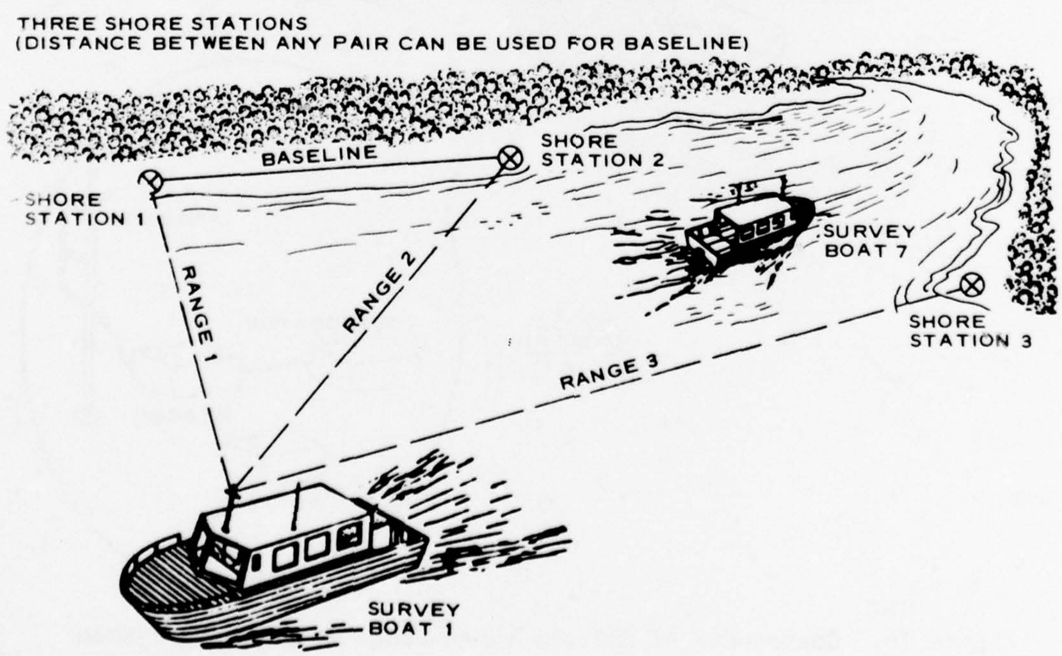

Figure 75. Three-range configuration of Syledis positioning system working up to seven survey boats

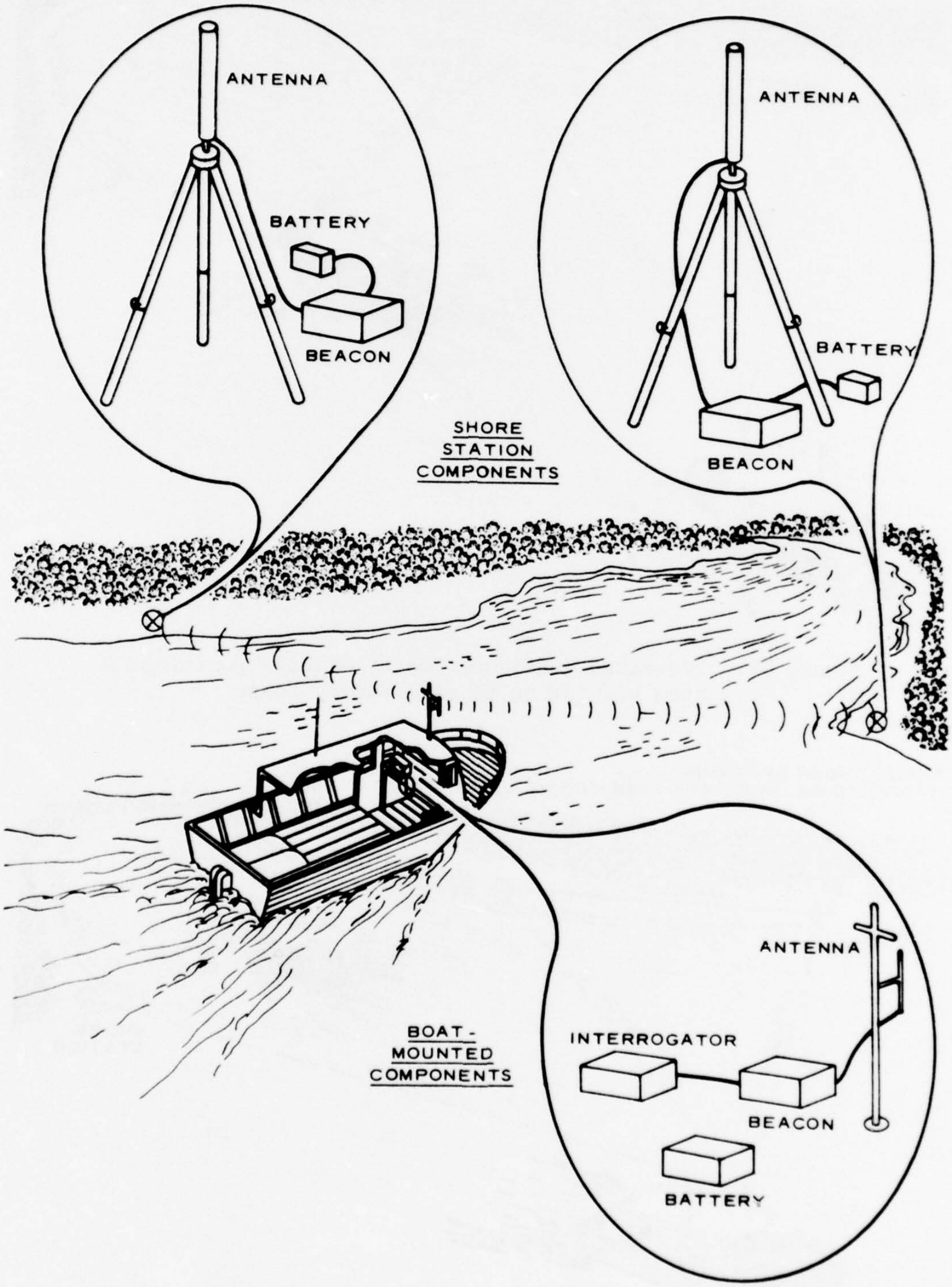

Figure 76. Components of Syledis range-range positioning system

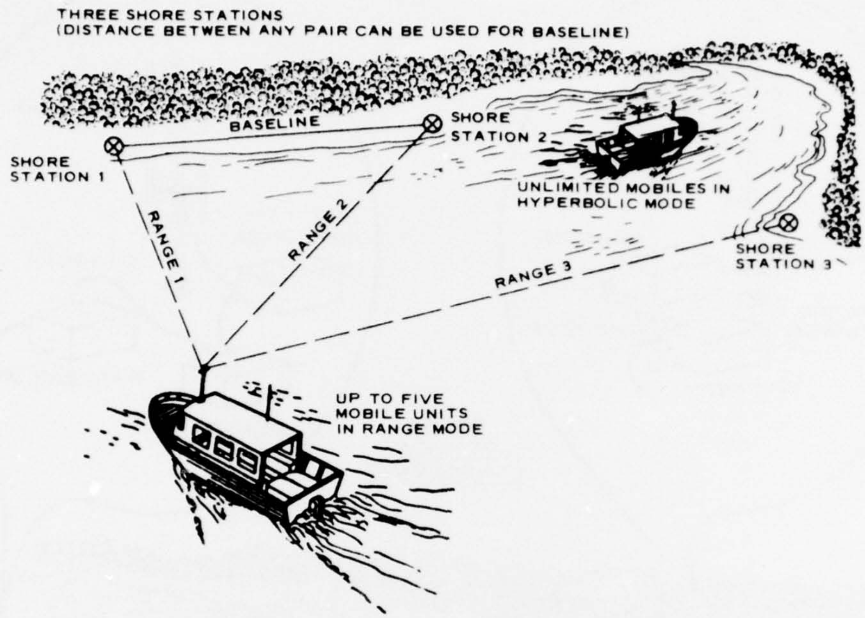

Figure 77. Syledis positioning system in compound mode operation

f. Power: interrogator--24-V DC at 4 A; beacon--24-V DC at 1.8 A; booster amplified--24-V DC at 10 A.

157. Sercel also manufactures booster amplifiers to give added range to the Syledis system as shown in Figure 78.

Toran

158. The Radio Navigation Division of the Sercel Corp. in France markets a radio frequency positioning system designed for offshore work under the trade name Toran. These systems operate at two frequencies in the 1.6- to 3.0-MHz band for the X-mode; four frequencies in the 1.6- to 3.0-MHz band for the Z-mode; or one frequency in the 1.6- to 3.0-MHz band and one in the very high frequency band for the V-, W-, or Y-modes. The operating frequencies of the Toran systems permit range beyond line-of-sight up to a maximum of 500 miles over water with a high-power option transmitter. The lower power transmitters allow ranges up to approximately 60 miles over water.

159. Toran positioning systems operate in the hyperbolic mode only (not range-range). The principle of operation of a Toran chain is

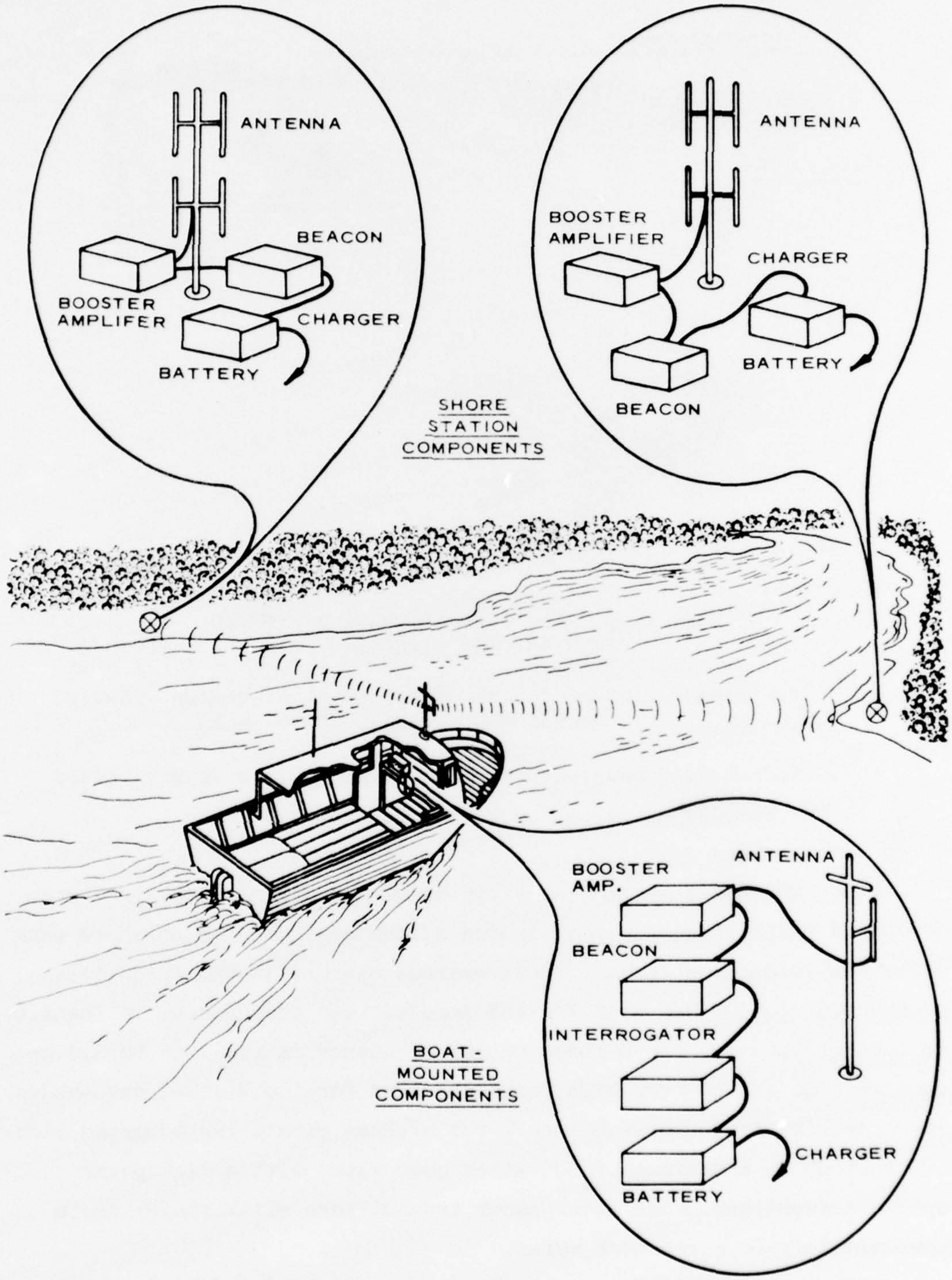

Figure 78. Components of Syledis range-range system with booster amplifier

as follows: Two continuous-wave (CW) signals that differ by a low frequency are radiated by two transmitters. A mobile receiver detects the beat frequency, its phase being proportional to the difference in distance between the mobile receiver and the two fixed transmitters. It remains constant along hyperbolae having these two stations as foci. In addition to this, a fixed receiver also picks up the beat frequency and transmits this signal to the mobile receiver as a phase reference. On board the mobile receiver, a phase meter measures the phase difference between the direct path signal and the reference signal.

160. The sensitivity of the equipment is good enough to detect 0.01 lane that corresponds to 1 m on the baseline. Resolution will be less than this in other parts of the hyperbolic pattern. Stability of the electronic pattern will be poorer over land than over water.

161. In addition to the basic positioning equipment, Sercel can supply associated equipment, such as track plotter, left/right indicator, digital clock, printer, tape punch, and magnetic tape recorder.

Crenco/Artemis

162. The Christiaan Huygenslaboratorium B. B. manufactures a microwave positioning system under the trade name Artemis. This system is unique in being the only microwave range-azimuth system commercially available. Artemis achieves a much higher angular tracking accuracy than is possible with one narrow beam antenna by using a technique in which the shore antenna and the boat antenna mutually track each other. This technique realizes an angular accuracy of 2 min of arc with antennas having 2-deg horizontal beam width. By using microwave angular tracking instead of optical tracking, the user circumvents the haze and fog limitations of all optical techniques. Since the antennas track automatically, the shore station can be unattended (except where equipment safety requires an attendant).

163. Being a range-azimuth system, this equipment accrues the advantages inherent in this approach compared with a range-range system. A range-azimuth system requires only one shore station instead of a

minimum of two with a range-range system. Where all shore stations must be manned for security reasons, reduction in this number equates to a significant cost savings. Another advantage with a range-azimuth system is the greater area coverage usually possible at a given site, since line-of-sight must be maintained to only one station instead of two. A third advantage of range-azimuth operation is that positional accuracy is less dependent on geometry than a range-range system. Figure 79 illustrates how an Artmis system could be used in a surveying application.

164. Artemis output can be electrically coupled to associated data loggers and boat guidance systems for typical hydrographic uses. The size, weight, and cost of the Artemis units probably will limit their usefulness to large boats.

165. Specifications for Artemis units are summarized below:

a. Operating frequency: 9.2 to 9.27 GHz.

b. Range: 50 m to 10 km; 50 m to 30 km optional.

c. Azimuth accuracy; approximately 0.03 deg.

d. Azimuth resolution: approximately 0.009 deg.

e. Distance accuracy: 1.5 m; 0.1 m optional.

f. Display: 5 digits, R-θ.

g. Electrical output: BCD, TTL.

h. Power: 24-V DC at 80 W.

i. Size and weight: antenna units--42 by 29 by 51 cm, 25 kg; control unit--52 by 22 by 34 cm, 14 kg; data unit--52 by 22 by 27 cm, 8 kg.

Associated Controls and Communications

166. Associated Controls and Communications, Inc. (ACCI), has demonstrated a microwave positioning system that uses passive shore reflectors instead of active shore transponders. This positioning system is basically a precision radar with reflectors located on the shore at known locations. Figure 80 illustrates this approach. In operation, a standard rotating antenna scans the shoreline, and reflected energy

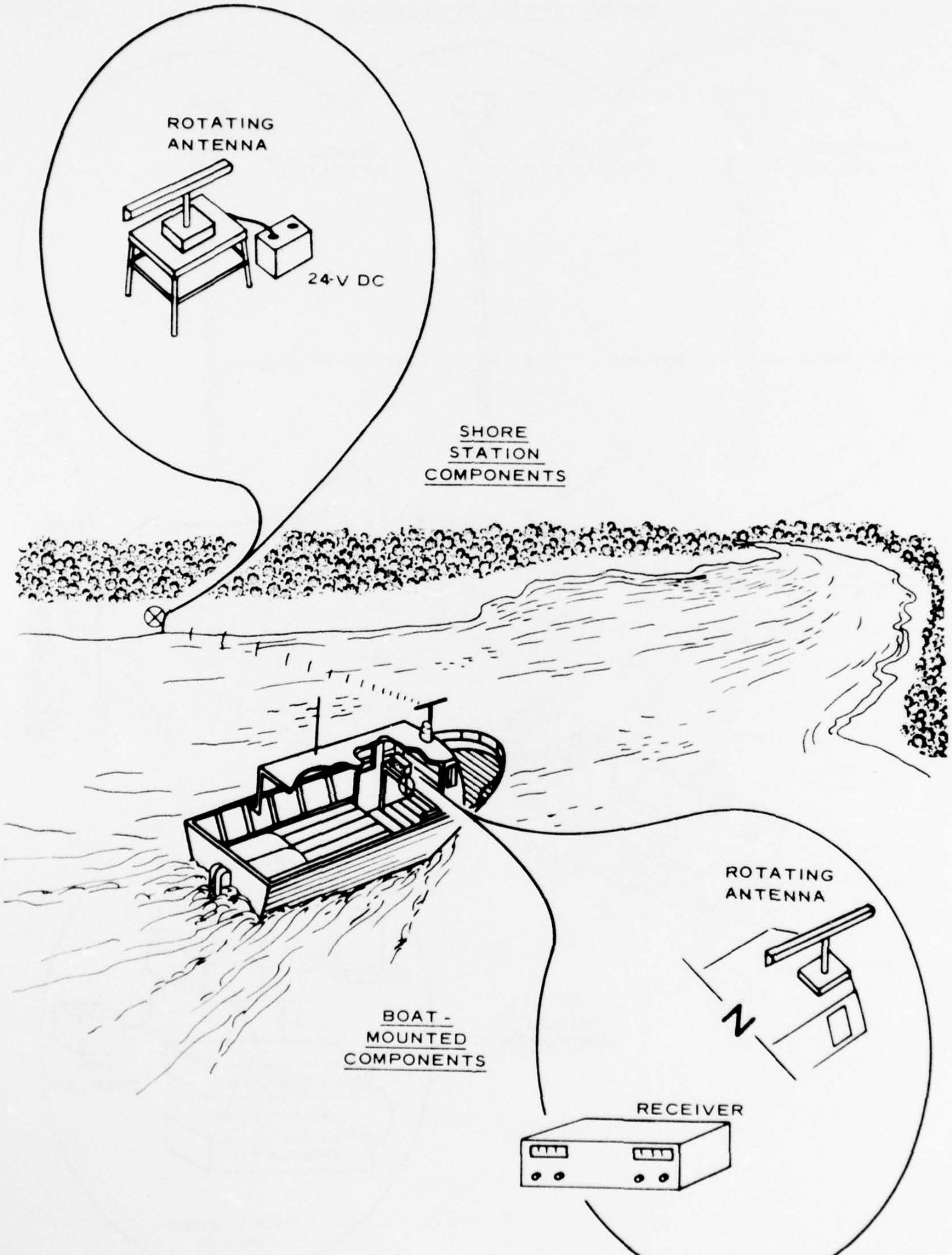

Figure 79. Components of Artemis range-range positioning system

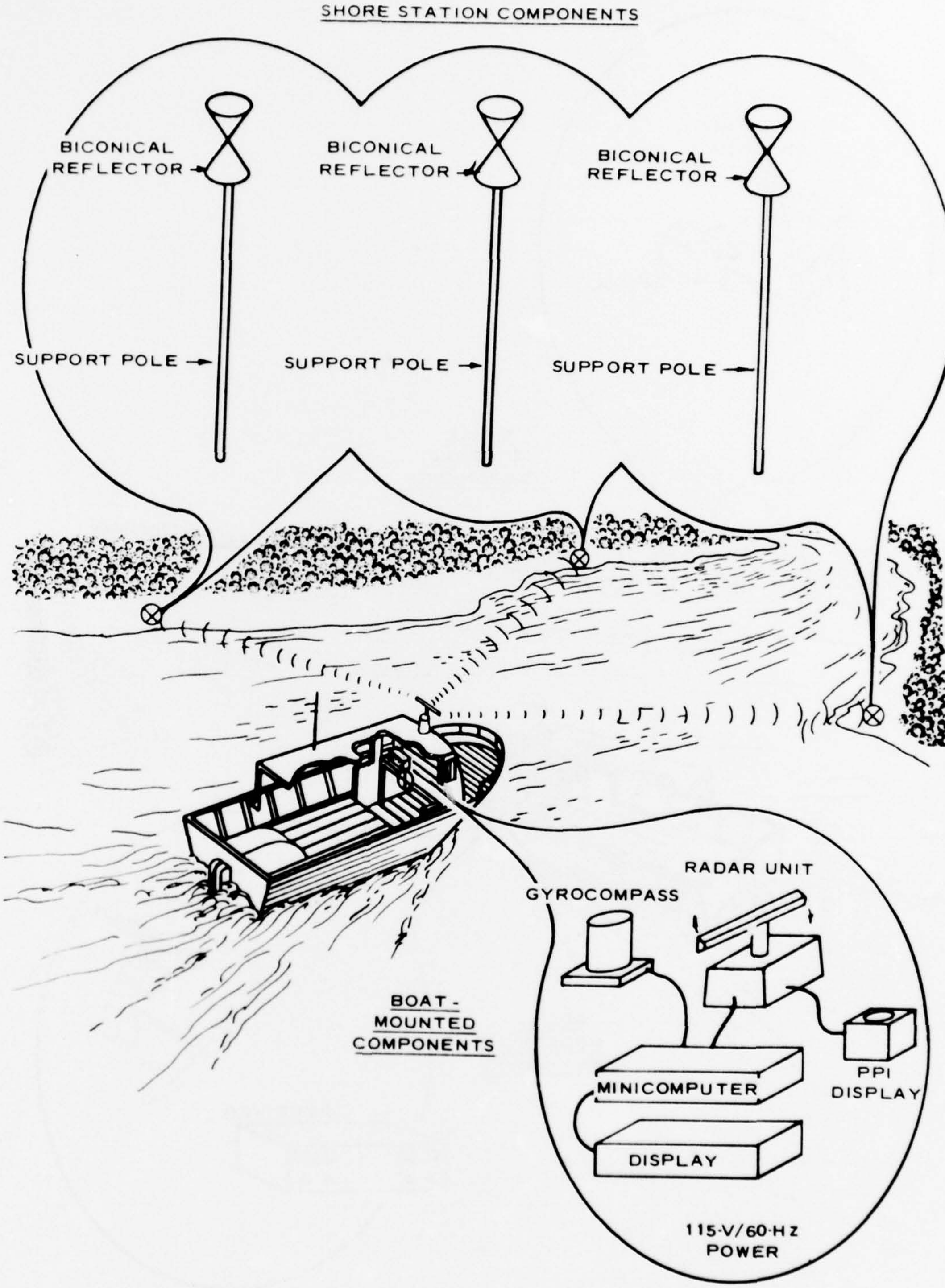

Figure 80. Components of ACCI passive reflector positioning system

is received between transmitter pulses. Metal reflectors, shaped to give a high return signal, provide received signals of higher amplitude than the surrounding natural shoreline clutter. The radar signal-processing circuits lock on to the reflectors and use gating techniques to distinguish between clutter and targets.

167. The use of passive reflectors instead of active transponders permits a number of alternate operational possibilities that are impractical with the latter approach. Passive reflectors are a small fraction of the cost of active transponders, relatively immune to damage other than severe weather and vandals, almost free of maintenance, and non-saturating. Due to their low cost and ruggedness, these reflectors can be permanently installed on the shore, much as visual aids for navigation are provided today. Use of permanently installed shore reflectors would eliminate the shore station setup time, except for initial installation and occasional repair. The low cost of installing passive reflectors also reduces the pressure to minimize the number of shore stations at the expense of good geometry.

168. A passive reflector/radar positioning system made by ACCI has been demonstrated aboard a New England Division boat in the Boston Harbor. Range resolution of approximately 6 in. was shown to be possible under the experimental conditions. This technique is still in the development stage, but it has the potential for widespread use within the Corps and by all inland marine waterway users.

Odom/Hydrobar

169. The Odom Offshore Corp. has developed a range-azimuth system to be marketed under the trade name Hydrobar. This system uses a manually tracked transit with electrical output for azimuth. The azimuth signals are transmitted from the shore tracking station to the survey boat by means of a telemetry link. A singe-range microwave DME operated in conjunction with the transit/telemetry components completes the range-azimuth system (Figure 81).

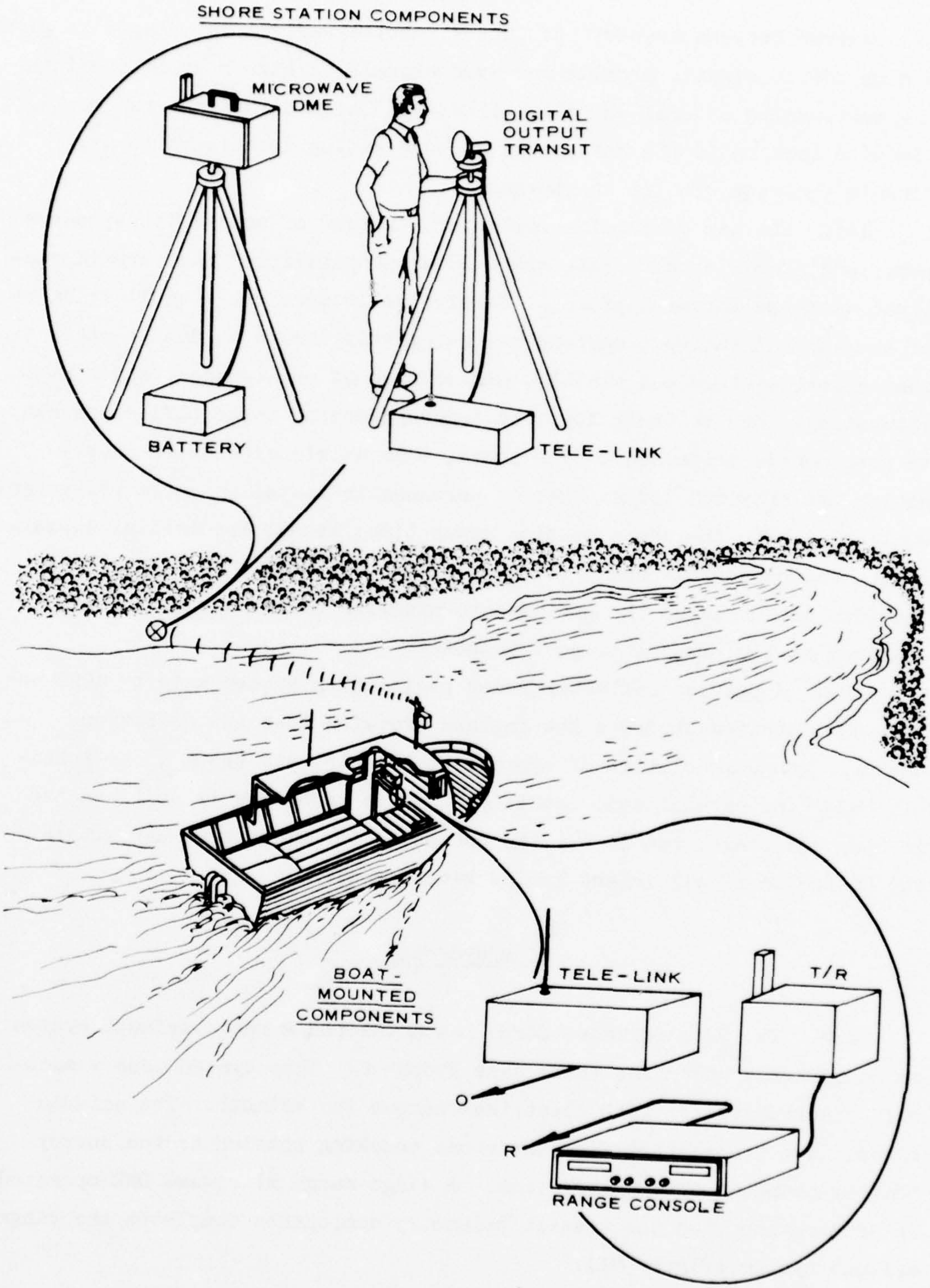

Figure 81. Components of Hydrobar range-azimuth positioning system

PART V: ACOUSTIC DOPPLER NAVIGATORS

General Description of Technique

170. Several companies market boat navigators that are independent of shore stations. The principle used in this equipment is the shift in frequency obtained when a source of energy is moving with respect to a receiver or reflector. The shift in frequency, known as the doppler shift, is commonly experienced when a person hears a train approaching or departing the listener's area. With doppler equipment, the received signal is higher than the transmitted signal when the transmitter and receiver are moving toward each other and is lower than the transmitted signal when the transmitter and receiver are moving apart. Doppler navigators can be built with optical, electrical, or acoustical energy, but for use on boats, acoustic energy is the only practical underwater technique. Microwave doppler navigators are used on aircraft in much the same configuration that acoustic doppler navigators are used on boats. Microwave energy will not penetrate underwater due to high signal attenuation but has low losses in air. Acoustic energy has the reverse situation--high losses in air and low losses in water. Thus, acoustic doppler navigators are well adapted to boats but impractical for aircraft.

171. For operation in a boat, the transmitter and receiver are both mounted in an assembly in the hull of the boat. The transmitter radiates energy reflected from the bottom and returns to the receiver on the boat. The received signal is shifted in frequency by the relative motion of the ship and the bottom, and the shift will be a direct function of the relative motion (Figure 82). For a practical design, the transducer assembly will contain components that face in opposite directions along each axis. The single T/R pair used to explain the principle is not adequate for a practical navigator because ship motion will introduce too much error in the results. By adding a second T/R pair, facing in the opposite direction, the configuration produced is relatively insensitive to boat motion (Figure 83). With this transducer

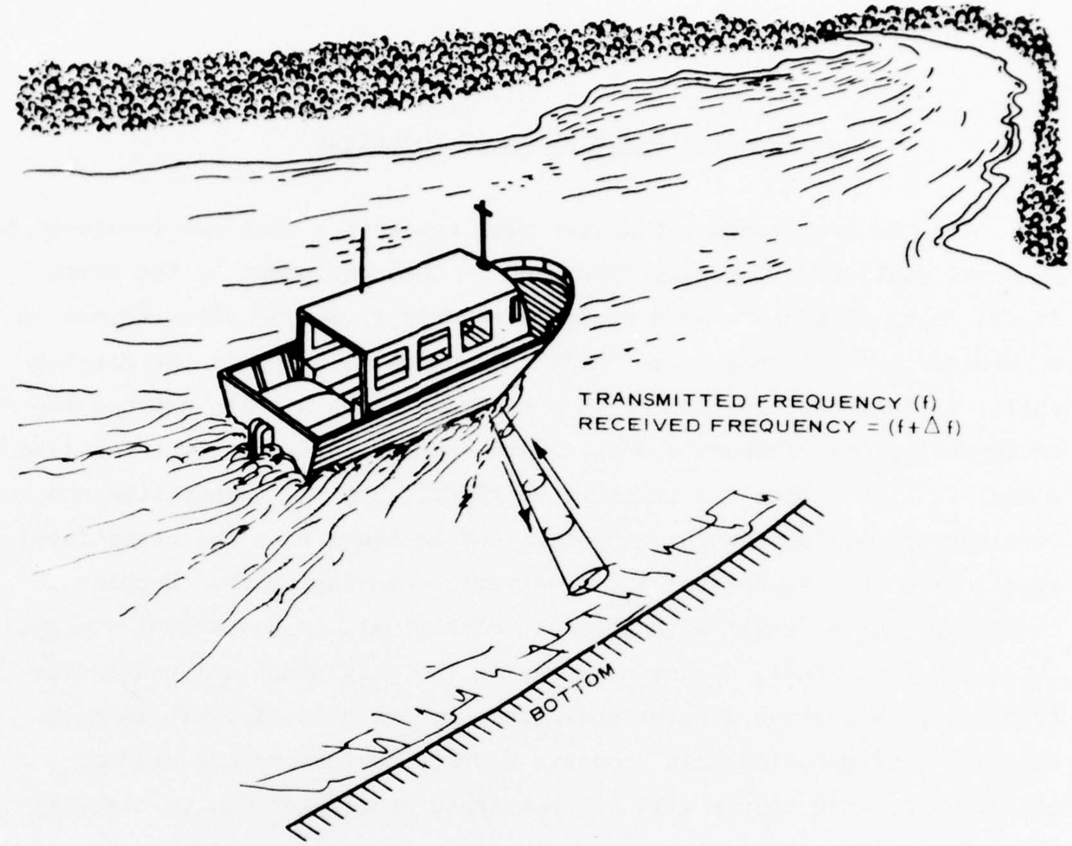

Figure 82. Principle of doppler navigator

arrangement, a very accurate bidirectional measure of boat velocity relative to the bottom can be obtained with appropriate electronics in the boat. The velocity thus derived is of sufficient accuracy to give a good displacement value when it is integrated with respect to time.

172. The single-axis transducer assembly measuring fore/aft velocity is insufficient for a doppler navigator since boats will have a significant port/starboard motion to consider when the boat velocity is integrated. To provide this information, a second set of transducers is added to the doppler system to measure the port/starboard component of boat velocity. The port/starboard transducer pair has the same angular orientation with respect to the vertical axis as the fore/aft transducer pair and equal insensitivity to ship roll and pitch. Figure 84 is a sketch of this four-beam configuration. Westervelt[3] gives a

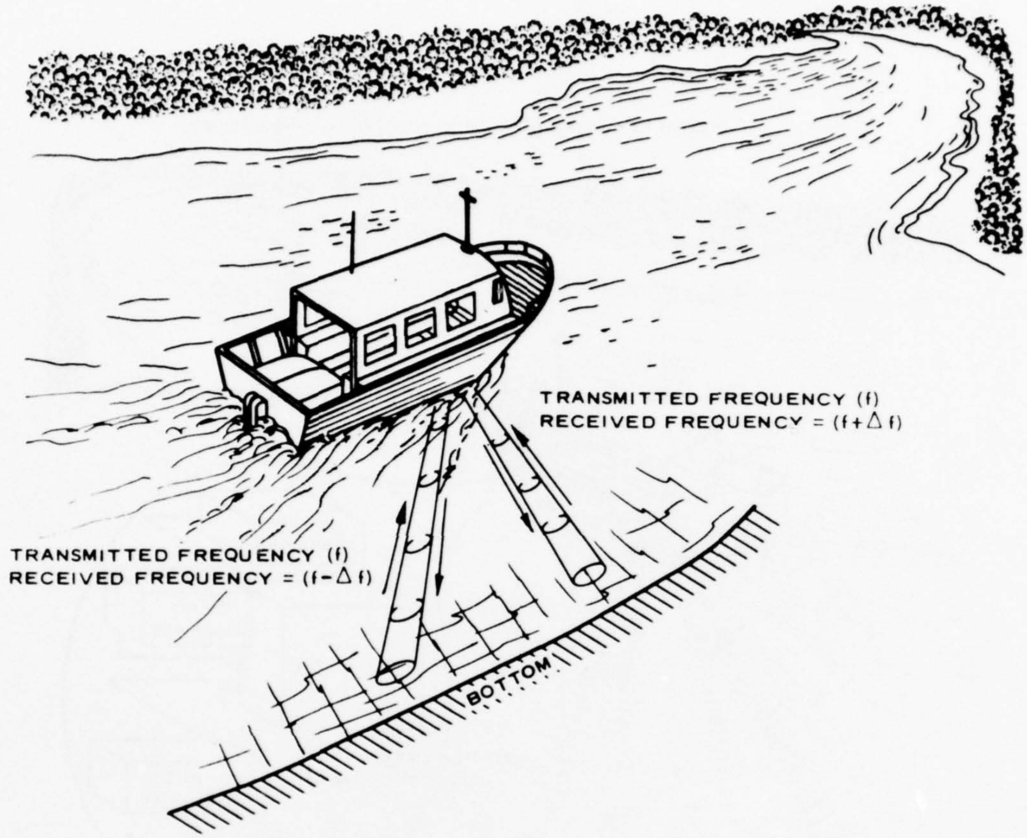

Figure 83. Doppler navigator with bidirectional transducer pairs

mathematical description of acoustic doppler navigators for a reader desiring additional information.

173. The four-beam configuration gives biaxial and bidirectional velocity information relative to boat motion, but one more input is needed in order to compute the boat course. Direction, the missing factor, can be supplied by a good quality gyro. Therefore, for boat navigation, a complete system will include a two-axis doppler system and a gyrocompass as inputs to a computer. The computer can integrate the course from a starting point and plot the position of the boat wherever it is piloted and without any reference other than a firm waterway bottom. This offers a considerable advantage since shore stations are not required except for a starting point reference and periodic checkpoints. By greatly reducing the need for shore stations, a doppler navigator can, in some instances, give versatility not possible with

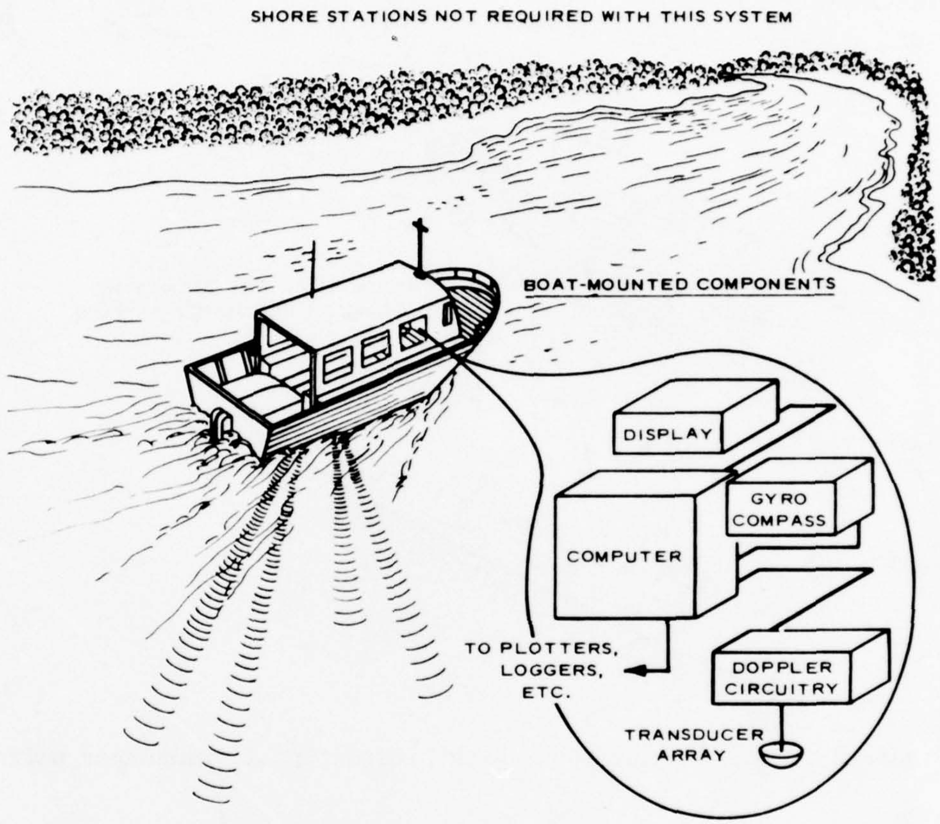

Figure 84. Four-beam doppler navigator system

electronic or optical DME. For instance, a boat can navigate around bends in rivers and harbors where the setup time for electronic DME would be very costly. A doppler navigator system can also operate offshore beyond reasonable line-of-sight conditions, such as hopper dredge guidance from a shoal area to a dumping ground. If other conditions are satisfied, a doppler navigator could provide this type capability much easier than electromagnetic DME.

174. The use of acoustic doppler navigators by the Corps has several significant and severe limitations. As a fundamental constraint, the integral of velocity is displacement but with an error that is cumulative with time. Thus, a boat navigating by this method will have an error proportional to the time increment between position checks. Another severe constraint is the stability of the bottom, since the bottom is used as the reference reflection. In many rivers, a layer of

sediment is moving along the bottom of the channel. This moving layer is highly reflective to acoustic energy and appears as a "false" bottom to the signal-analyzing circuits (Figure 85). Since the doppler shift is

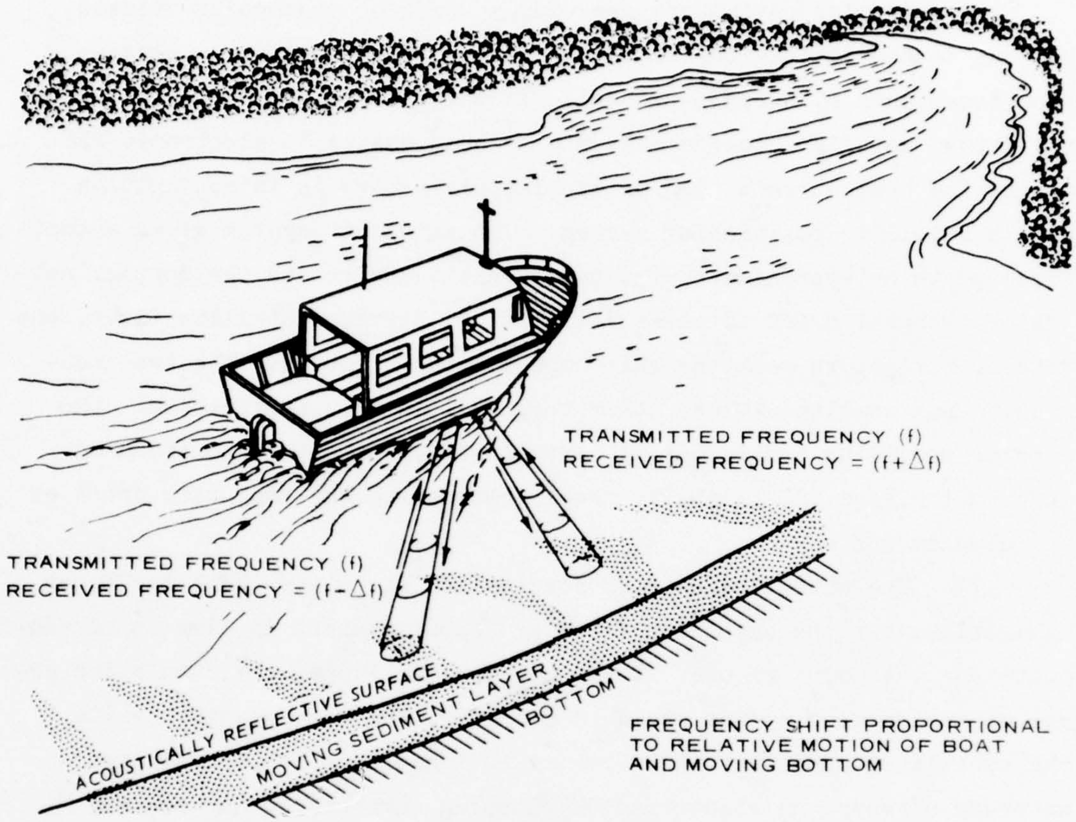

Figure 85. Moving bottom effect on doppler velocity system

derived from the relative motion of the boat and the bottom, as determined acoustically, then the true velocity of the boat will be in error by the velocity of the moving bottom. This effect limits the use of doppler navigators to offshore areas or to inland waterways where very little sediment is being transported.

175. Another constraint to consider is the depth range over which an acoustic doppler unit is effective. For offshore work, the water depth may become too great for the reflected signal to be detected, and the signal processing equipment will shift to water-track mode and give reduced accuracies. Some doppler equipment designed for deepwater work generally uses lower frequencies to get lower signal attenuation and

thus has reduced accuracy as a result of this compromise.

176. Doppler navigators are widely used for oceangoing vessels, but due to the limitations mentioned above, they have found relatively slow acceptance by Corps personnel. In the future, however, doppler navigators may find considerable use as supplements to electronic DME. One of the best current uses of doppler navigators is in conjunction with a satellite positioning system. The satellite system gives a position update on approximately an hourly basis and resets the doppler navigator integral drift to essentially zero. Between satellite fixes, the doppler navigators keep the ship so equipped on course. The two techniques thus complement each other very well in this application: the doppler providing continuous high-resolution, short-term positioning information, and the satellite system correcting the long-term drift of the doppler system.

177. The satellite/doppler combination works very well for ocean navigation, but the satellite fixes are too far apart in time to be adequate for the Corps to use. In an hour's time lapse, the cumulative error of the doppler system would be too great for survey work. While the satallite/doppler combination may be inadequate for many inland waterway surveys, an electronic DME/doppler combination may be very useful in some instances. A doppler navigator operated in conjunction with a microwave DME would extend the area of coverage of a given set of shore stations. Furthermore, the doppler unit could maintain course through blind spots, interference zones, and areas of poor DME geometry. Westervelt[3] gives a mathematical analysis of doppler signals.

Commercial Equipment

Edo Western

178. The Edo Western Corp. manufactures several different types of doppler velocity systems for marine use. These include: Model 435 pulse doppler sonar navigation system for oceangoing ships, Model 482A docking system, Model 582C doppler speed log, Model 683 doppler water velocity system, and Model 4049 doppler current meter.

179. Model 435 will supply continuous measurement of boatspeed and distance moved over the bottom. It is compatible with satellite navigation systems where this combination is considered desirable.

180. Model 482A designed for use on very long ships, such as super tankers, has both a stern transducer assembly and a bow transducer assembly. With this system, the pilot can get a better indication of the relative motion of the extreme ends of the ship with respect to the shore than with a single transducer assembly.

181. Model 582C is a single-axis, lower cost instrument designed to be a piloting aid.

182. Model 683 can provide biaxial boatspeed relative to the bottom and, in addition, can measure the velocity of the currents in the water underneath the boat. The operator can select the depth at which a water velocity reading is desired by means of the front panel control. The water velocity measurement section uses the same type of signal-analyzing circuits as the water-track mode but with the addition of an operator-controlled time gate. By setting a time gate at a certain value, the operator selects the depth from which the reflected acoustic energy is analyzed. The time gate width can separate the underwater space into approximately 10-ft layers with the center of the gate adjustable in 1-ft increments. The output from this instrument is more accurate than mechanical instruments, and the measurements can be made in a much shorter time than would be necessary with instruments that require lowering on cables.

183. Model 4049 combines a single-axis doppler intervalometer with a depth measurement system. Instead of recording depth on a time-base record, this system records depth as a function of distance traveled. Thus, the charts do have to be converted from time base to distance base as with a conventional recorder. A survey boat, equipped and piloted to run a straight course perpendicular to a channel, will make a direct plot of the channel cross section.

Raytheon

184. The Raytheon Corp. manufactures a doppler speed log (Model DSL-200) that can provide the pilot with speed indication from

reflections as deep as 1000 ft. The unit has a speed resolution of 0.01 knot in shallow water and an accuracy of 0.5 percent. Speed information can be viewed at three remote digital display panels.

PART VI: MISCELLANEOUS POSITIONING EQUIPMENT

Satellite Navigation Systems

185. Satellites designed for marine navigation have been in orbit for several years and are currently available ocean navigation tools (Figure 86). As it now exists, the satellite system provides position

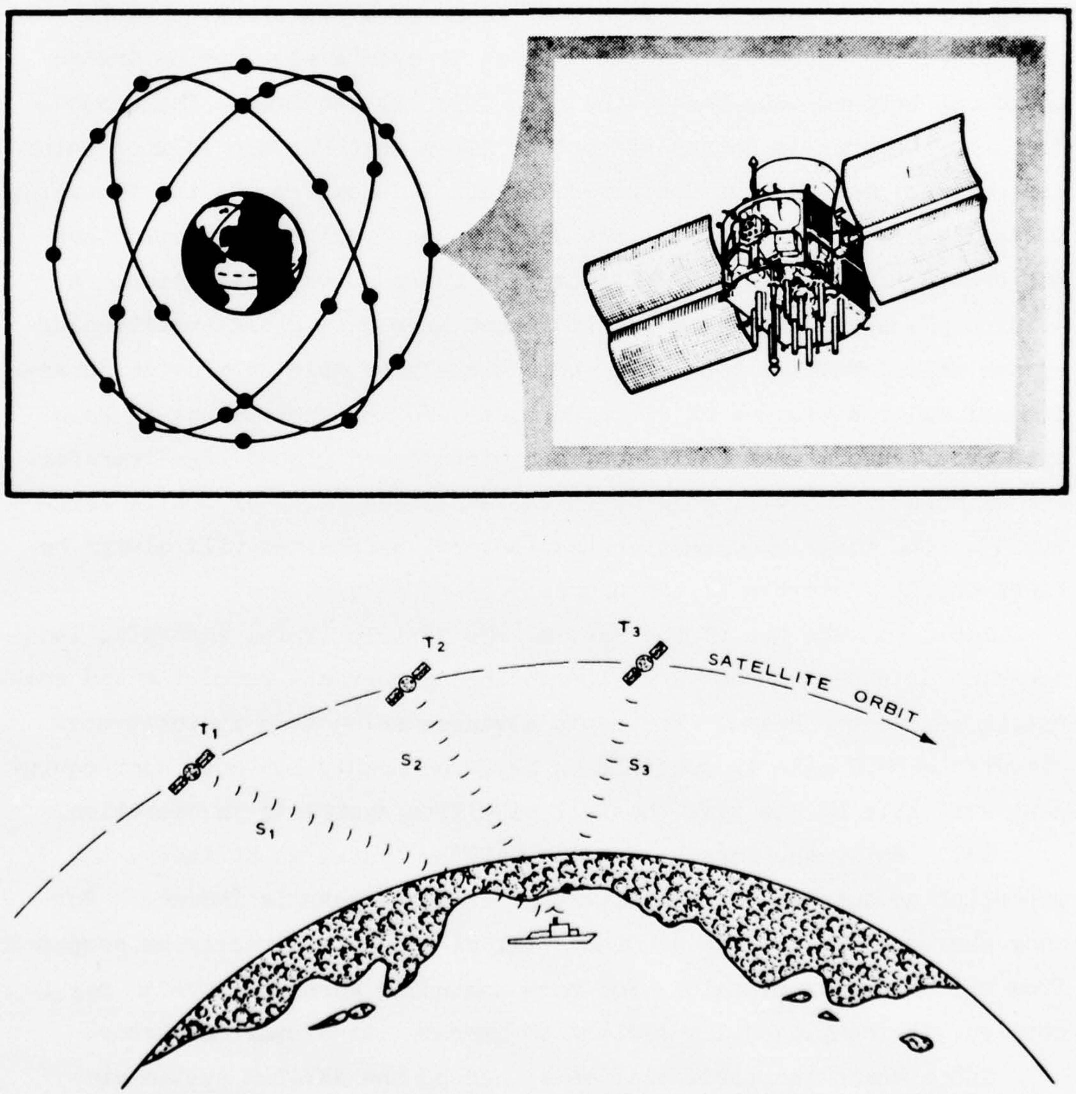

Figure 86. Current satellite navigation system

updates at approximately 1-hr intervals, which is adequate for many ocean-shipping uses. The doppler navigator provides position information between satellite fixes, and the satellite fixes reduce the doppler navigator cumulative errors to no more than those occurring in the 1-hr interval. Thus, these two types of positioning equipment complement each other very well and appear to be an excellent addition to the techniques available for ocean navigation. Nevertheless, this system, like Omega, does not meet the needs of Corps survey work in inland waterways because of inadequate accuracy. For instance, the satellite up-date time of 1 hr is completely out of the realm of a practical operating time frame for the Corps. A survey boat or even a slow moving dredge could run aground long before the next "fix" is received. The acoustic doppler navigator is not an adequate fill-in unit for use in most inland waterway for the reasons discussed in Part V. However, in the future, a satellite system already in the design stage will be developed that has promise for making a major impact on Corps survey navigation. A joint U. S. service program has initiated work on a global positioning system called NAVSTAR that will theoretically be able to provide three-dimensional positioning of ±10 m vertical and ±8 m horizontal in both axes, boat velocity of ±0.1 knot, and microsecond global time transfer. The NAVSTAR system will consist of 24 satellites in 12-hr orbits (Figure 87) with their spacing such that several satellites will always be electronically visible to the users.

186. To make use of the system, the vehicle (ship, aircraft, land vehicle, or undersea craft) will need the appropriate receiving and computing equipment aboard. The rapid advances being made in integrated circuits should make it possible to have reasonably low-cost user equipment available by the time the full satellite system is in operation.

187. While the impetus for the NAVSTAR system is military, the potential advantages to nonmilitary government users is immense. For many survey purposes, the accuracy will be adequate directly as computed from the satellite signals. For more demanding work, the system may be coupled with complementary systems to improve its overall accuracy.

188. While the possibilities opened by the NAVSTAR system are

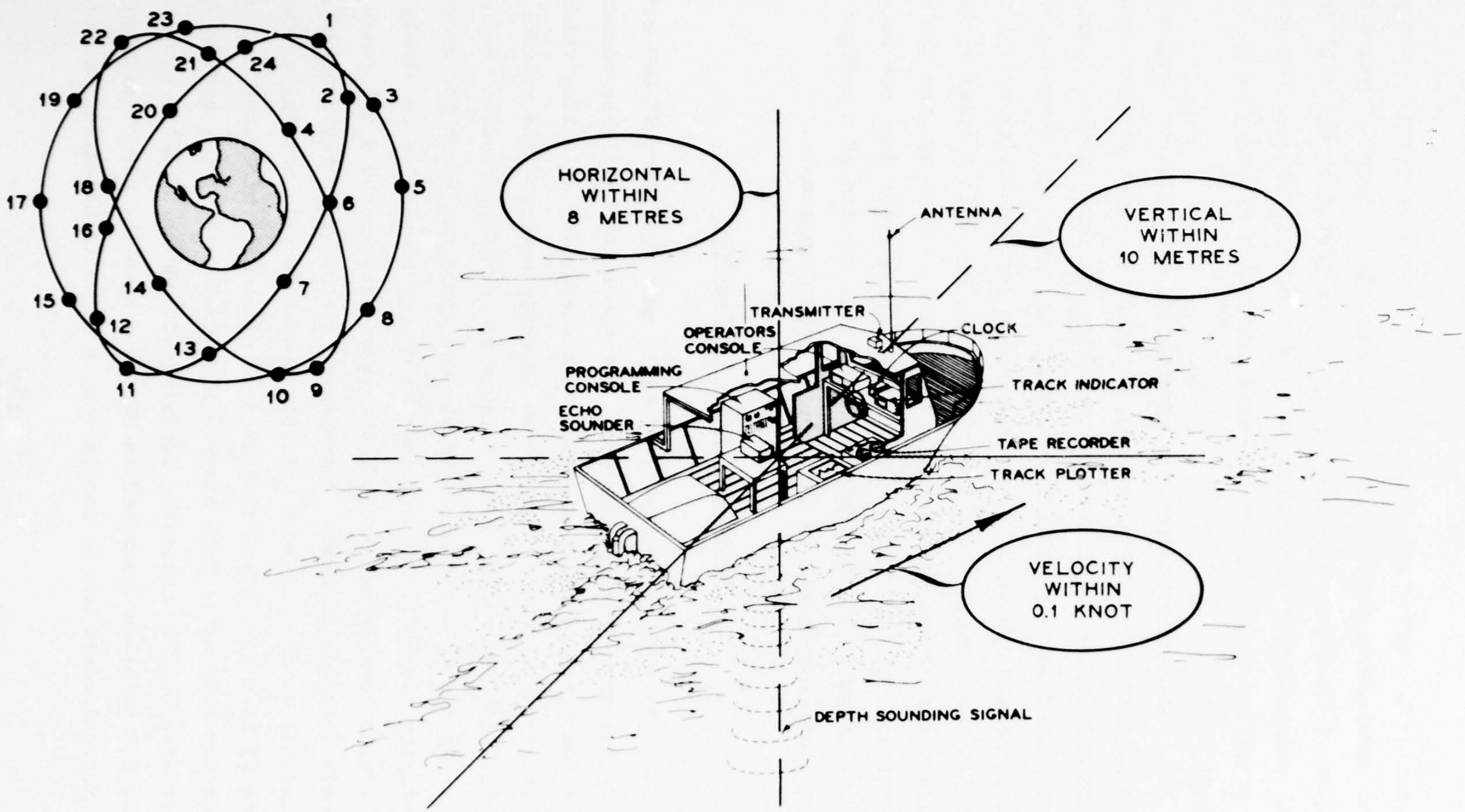

Figure 87. NAVSTAR satellite navigation system

fascinating to contemplate, consideration should be given to the projected development schedule. It will probably be about 10 years from the date of this report before the system is providing the full operational capability of the design goal. Current operational requirements must therefore depend on ground-based navigation systems for at least the next decade.

189. Several companies are advertising commercially available satellite systems. The Magnavox Corp. manufactures both doppler sonar navigators and marine satellite navigation systems and combines them into an integrated doppler/satellite positioning system for seagoing vessels. The combination system provides continuous dead-reckoning position information from measurements supplied by the acoustic doppler system. As satellite passes are received, the satellite section updates the ship position so that the dead-reckoning cumulative error does not become serious. Figure 88 illustrates a commercial version of a navigation system combining satellite and doppler sonar components.

Microwave Doppler Navigators

190. Doppler navigators are widely used for aircraft and watercraft guidance at the present time. Of the units available commercially, all of the aircraft units use microwave energy for detecting velocity, and all of the watercraft units use acoustic energy. The reasons for this distinct separation in techniques are straightforward. Acoustic energy has a high attenuation in air and could not reach the ground from high-flying aircraft. Also, acoustic energy propagates so slowly that even from a low-flying aircraft the ground return could not reach the aircraft detector in time. Conversely, microwave energy propagates efficiently in air and at a velocity that fits well with aircraft speed. Figure 89 is a simplified diagram of a commercial microwave doppler navigator for aircraft. This diagram illustrates the close analogy between a microwave doppler navigator for aircraft and an acoustic doppler navigator for ships as described in Part V. When the use of microwave energy for shipboard use is considered, a converse situation exists.

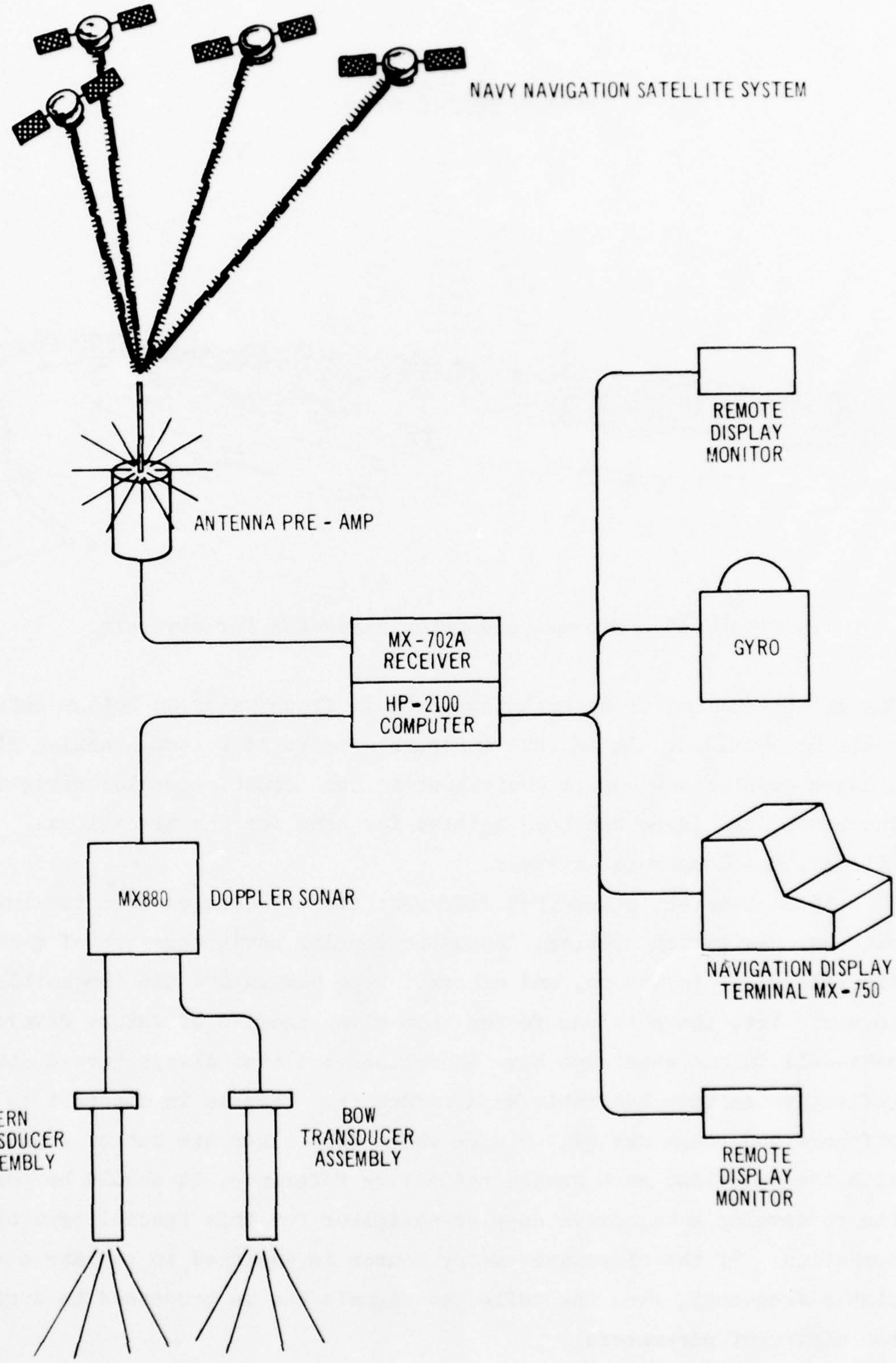

Figure 88. Commercial version of a navigation system combining satellite and doppler components

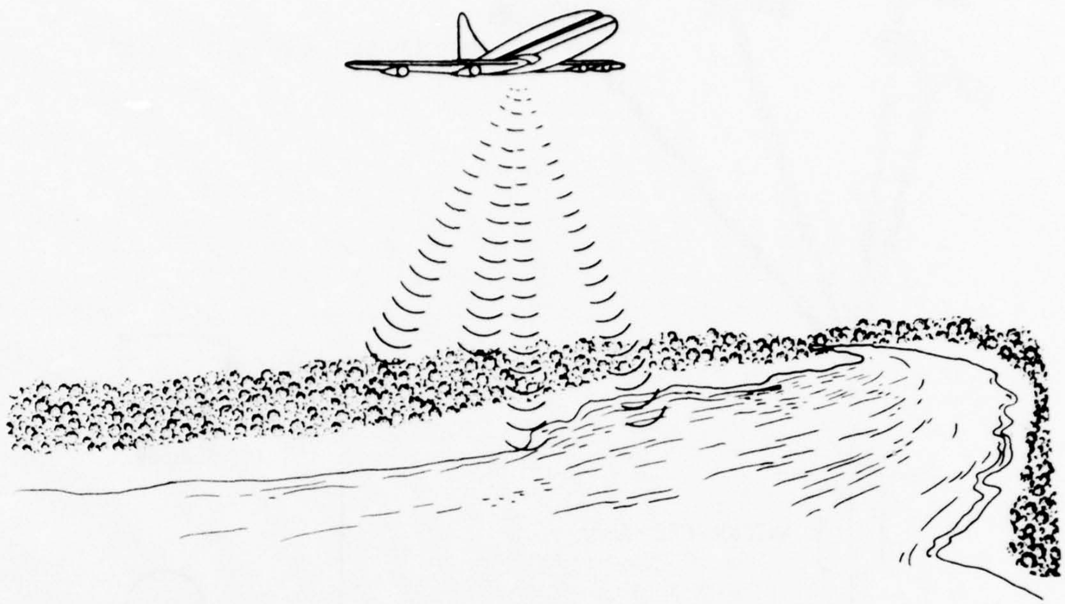

Figure 89. Microwave doppler navigator for aircraft

Signal attenuation is so high that even in fresh water no bottom return could be obtained. It is thus impossible to build bottom-tracking microwave doppler navigators equivalent to the acoustic doppler navigators. Therefore, the issue has been settled for some for the traditional military and commercial markets.

191. However, a somewhat different picture emerges from the inland waterway navigation problem. Acoustic doppler navigators are of questionable value in rivers, and aircraft-type navigators are impossible to use. Yet, there is one factor that gives promise of future development--all inland waterways have shorelines and thus always have a stable reflective surface available as a reference. This is in contrast to offshore and ocean navigation work where shorelines are out of sight. With the shoreline as a stable reflective reference, it should be possible to develop a microwave doppler navigator for this special type of operation. If the microwave energy source is designed to radiate a very stable frequency, then the reflected signals can be processed to derive two different parameters:

a. The distance to the shoreline as with conventional radar.

b. The velocity of the boat with respect to selected segments of the shoreline by measuring the doppler shift in the received signal.

By combining two or three velocity vectors derived from the special radar, with information from the gyro headings, the ship movement could be calculated.

192. This concept is no more than an early idea advanced to stimulate the design effort of manufacturers and the interest of government personnel in seeking new methods. The proposed doppler system would permit inland waterway survey boats the freedom of operation given by acoustic doppler navigators to offshore ships and by microwave doppler navigators to aircraft. However, for current Corps operational requirements, only established techniques and equipment should be considered.

Laser and Optical Systems

193. Laser tracking systems have been used for the determination of aircraft and ship positions by a number of different organizations. Compared with microwave systems, laser systems can provide improved accuracy and are immune to radar-type interferences. A single ground-based system can provide azimuth, elevation, and range to a target equipped with a suitable retroreflector. Laser systems thus offer attractive possibilities for some special navigation or positioning applications. A good example of a laser system of this type is the precision aircraft tracking system built by GTE Sylvania (see Appendix A).

194. The GTE Laser Aircraft Tracking System (Model A-18) operates on the principle illustrated in Figure 90. A high-power laser beam is transmitted so that it intercepts the retroreflector located on the moving vehicle. The laser beam is used to measure range by transit-time determination in the electronics and also to provide a tracking signal to the azimuth and elevation servomotors. The tracking unit is guided manually until it locks on a target; following this step, the tracking is automatic.

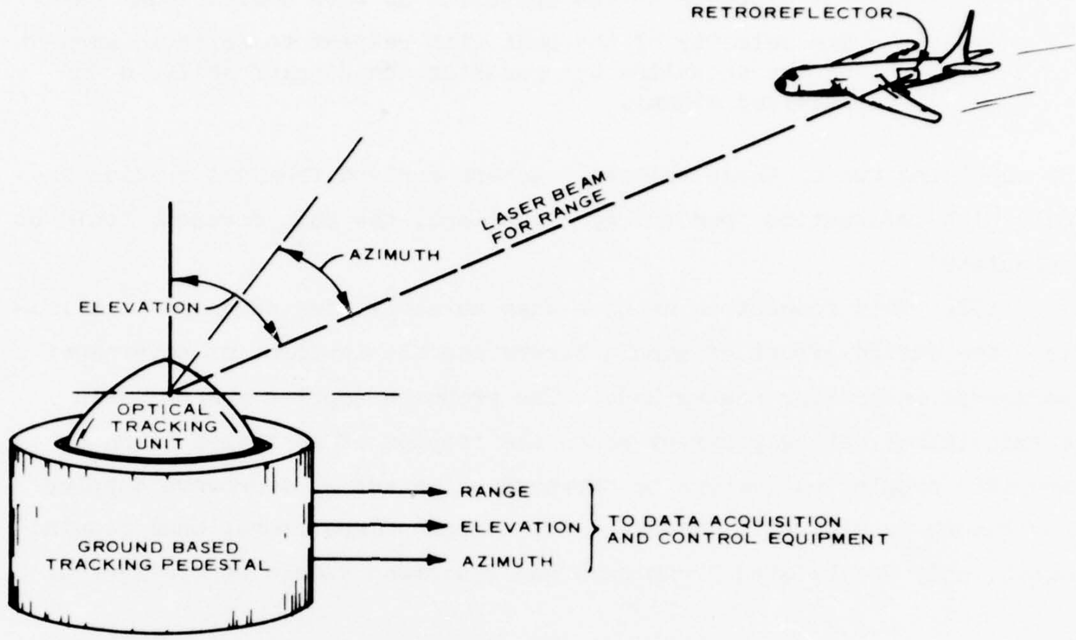

Figure 90. GTE Laser Aircraft Tracking System

195. Not all of the laser to microwave comparisons are favorable, however. Laser systems are rendered ineffective by such atmospheric conditions as fog, haze, rain, and snow, which are generally of minor concern to microwave or radio frequency navigation systems. These limitations are prohibitive for most survey boat operations since fog and haze, in particular, are so frequently encountered. Another negative factor is the cost. An automatic laser tracking system would probably cost in excess of $100K for a unit suitable for boat positioning. Also, the potential danger of eye damage from the high-power lasers necessary to achieve reasonable range makes the system unattractive. For aircraft, the upward-looking angle of the laser scanner minimizes this problem, and practical use of this technique is then possible. For surface work, the scanning would be at eye level and thus unsuitable.

196. An optical tracker that does not use a laser light source was built by Sanders Associates (see Appendix A) as an alternate technique. The Sanders Associates tracker (Model GNS-20N) has a flashing beacon for tracking purposes. The beacon will not hurt the eyes but gives no range information. Range information must be acquired from another type

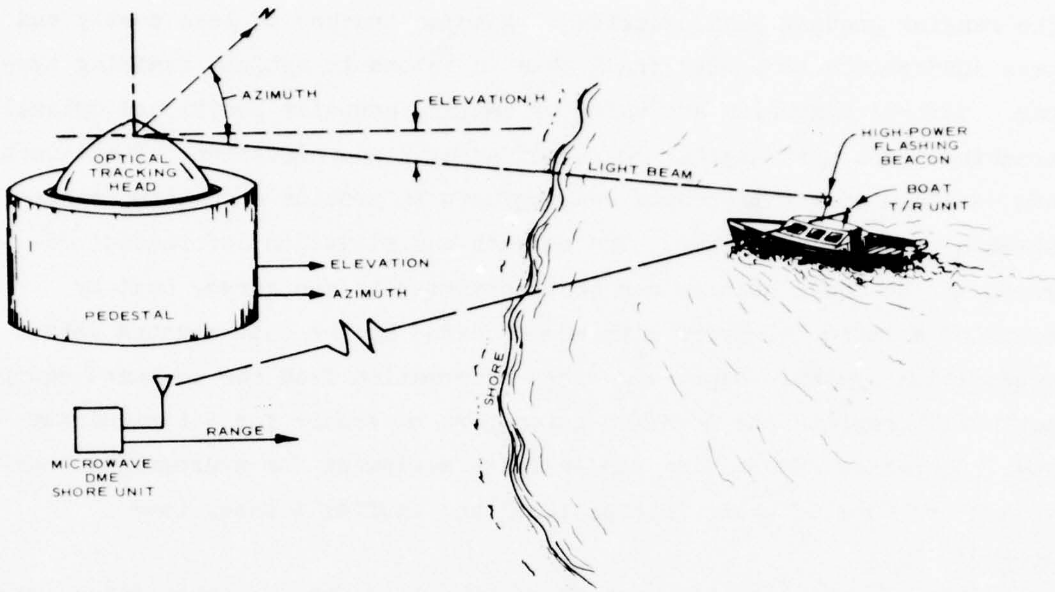

Figure 91. Beacon tracking system with separate DMU

of DME, such as a microwave DMU. Figure 91 illustrates this system.

197. The comments regarding safety and cost do not apply to the optical DMU designed for static or land-surveying operation. This type of optical DME uses low-power lasers or light-emitting diodes that will not cause eye damage. Volume production has also lowered the cost of optical surveying instruments to a level that this type unit can be very cost effective for measurements involving large areas.

198. A few of the manually positioned optical DMU can be used for dynamic measurements under some conditions. The Hewlett Packard 3810A, for instance, has a tracking mode that permits this unit to read distance to a moving target once it is "locked on." Maintaining the retroreflector target on a moving boat within the DMU optical field-of-view would probably be very difficult except under ideal conditions. Optical ranging with manual positioning of the DME unit is thus not considered a promising approach with currently available equipment. If optical DME with a broad beam width is developed and marketed in the future, then this limitation will be minimized.

199. Manual tracking of the azimuth and elevation of a moving boat with an optical surveying unit is a completely different situation from

the ranging problem just described. A human tracker is less costly and less susceptible to losing track than an automatic optical tracking system. Several companies are using or selling manually positioned optical tracking units with digital output of azimuth and elevation. These units are combined with a microwave ranging unit to provide a combined range-azimuth positioning system. The azimuth and elevation information derived at the shore station can be transmitted to the survey boat by means of a radio telemetry link and recorded by the boat-mounted data acquisition system. Depth and range information from the on-board equipment will complete the measured parameters necessary for a typical survey. Companies advertising rang-azimuth equipment for hydrographic surveying are Odom Offshore International and Keuffel & Esser (see Appendix A).

200. A commercially available alternate to the sextant method (see Figures 13, 14, and 15) is the angle-positioning instrument (Model GNS-22P) offered by Sanders Associates under the trade name Code-Lite. This instrument projects a 8-deg-wide by 6-deg-high light beam, which can be visually sighted or electrically detected up to 1 mile (Figure 92). The beam is divided electro-optically into a left sector and a right sector that combine to form a center track 20 to 40 sec wide. Boat-mounted equipment can detect the beam and give the pilot left/right guidance signals. Both the shore and boat units are battery operated so that field operation from small boats is practical. The narrow-beam tracking problem associated with land surveying instruments is avoided by the wider beam angle (8 deg compared with approximately 1 deg) of the Code-Lite, but at the same time a very narrow center-line tracking path can be detected.

Compound Hydrographic Surveying System

201. Of the positioning systems described previously, each has limitations restricting its use in some facet of hydrographic surveying. Therefore, none of them can be called a universal system. It can be predicted that there probably never will be a "universal" system that will meet all the diverse needs of a given District. For some Districts,

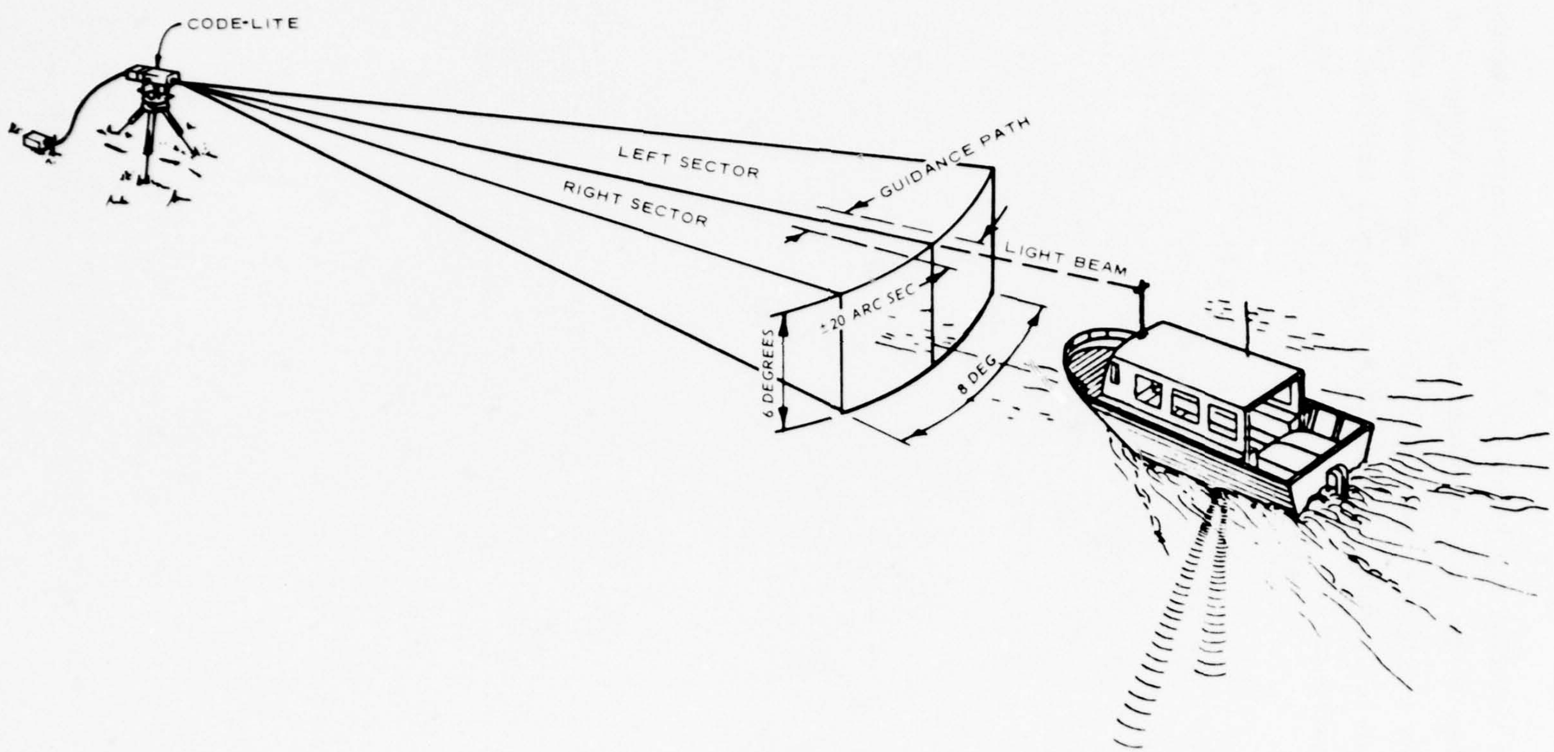

Figure 92. Angle-positioning instrument called Code-Lite

a reasonable solution may be the procurement of several separate systems to be operated in District geographical areas. For others, an optimum choice may be a compound hydrographic surveying system combining two or more types of positioning systems into an overall unit that has a minimum of limitations.

PART VII: INTERFACING POSITIONING SYSTEMS WITH DATA ACQUISITION AND CONTROL SYSTEMS

General

202. The selection and use of an automatic positioning system will usually be closely coupled with additional automatic equipment that measures depth, records measurements, and in many cases, provides pilot guidance. The preceding parts of this report have emphasized the positioning system to be used, but its selection must also consider the associated equipment necessary to complete an automatic hydrographic survey system. In order to provide a unified report, a brief description of complete hydrographic survey systems and the primary factors affecting their application will follow. The complete system selection will be governed by (a) degree of field automation desired, (b) cost of equipment, (c) boat size, and (d) procurement constraints. Each case will require a compromise between these frequently conflicting constraints. A broad range of functional capability is available in today's hydrographic survey systems, so the user can select a system closely matched to the needs of a specific application and obtain an optimum compromise of the total system constraints. Figure 93 categorizes hydrographic survey system capabilities according to output functions and also lists major suppliers to show which functional markets individual manufacturers are supplying. Such a tabulation gives only a limited summary of functional differences between systems, and individual manufacturers should be consulted for the many options and operating functions. Software is included by all the system suppliers as a component of their systems. Considerable differences exist in the software and should be considered even though it is not included in the categorization.

203. For many operations, the type of waterway determines the size of boat to be used for surveying. Large estuaries require large boats for safe operations in the waves and weather that may be encountered. Small channels prevent the use of large boats because they cannot maneuver adequately. This constraint is fundamental and should be of prime consideration in system design.

System Category	Principal Output Functions	Decca	Hydro-Carta	Teledyne	Motorola	Cubic	Ross
Computer controlled	On-line computer drawn charts Steering indicator Tape recording	X	X	X	X	X	X
Computer controlled	Track plotter for pilot guidance Steering indicator Tape recording	X	X	X	X	X	X
Microprocessor or calculator controlled	Track plotter for pilot guidance Steering indicator Data recording	X			X		
Large-boat data logger	Computer compatible magnetic tape data record				X	X	X
Small-boat data logger	Digital cassette data record			X			
Dredge positioning	Position plotting	X	X	X	X	X	

Figure 93. Hydrographic survey system categories

204. Computer-controlled survey systems offer great capability and versatility, but they are inherently large and bulky; thus, one of their constraints is that they can best be installed on relatively large survey boats. (It is conceded that some Districts have done a remarkable job of "shoe-horning" computer-controlled systems into medium-sized boats.) Small-channel surveying, therefore, generally is restricted by default to a data-logging system instead of a computer-controlled system.

Large Survey Boat Computer-Controlled Systems

205. The most sophisticated hydrographic survey systems are mini-computer controlled. These systems offer the greatest degree of versatility and can perform very complex functions automatically. The use of computer-controlled hydrographic survey systems has been reported at each of the four annual Corps hydrographic survey conferences conducted (as of this date) from 1972 through 1975.[4-7] Brief descriptions of computer-controlled survey systems are included in this report in the sections on Teledyne, Decca, and Hydrocarta. The largest of the computer-controlled systems feature on-line plotting of the survey data and, thus, provide the fastest possible access time (Figure 94). Other computer-controlled systems are intended primarily for pilot guidance and data recording with postsurvey plotting capability (Figure 95).

206. Districts known to be using on-line data-plotting systems or to have them planned for procurement are Norfolk, Memphis, Philadelphia, Portland, Tulsa, Wilmington, Savannah, New Orleans, and Mobile.

207. The Norfolk District has probably been operating an on-line computer-controlled system for the longest time of any of the Corps Districts. This system in its original form was an adaptation of an earlier NOAA computer-controlled system for offshore work. Norfolk personnel modified system components and software to meet their specific needs. The operations of this District are primarily coastal, and the software is adapted to this type of service. The positioning system used is a Raydist because District personnel felt that this system best

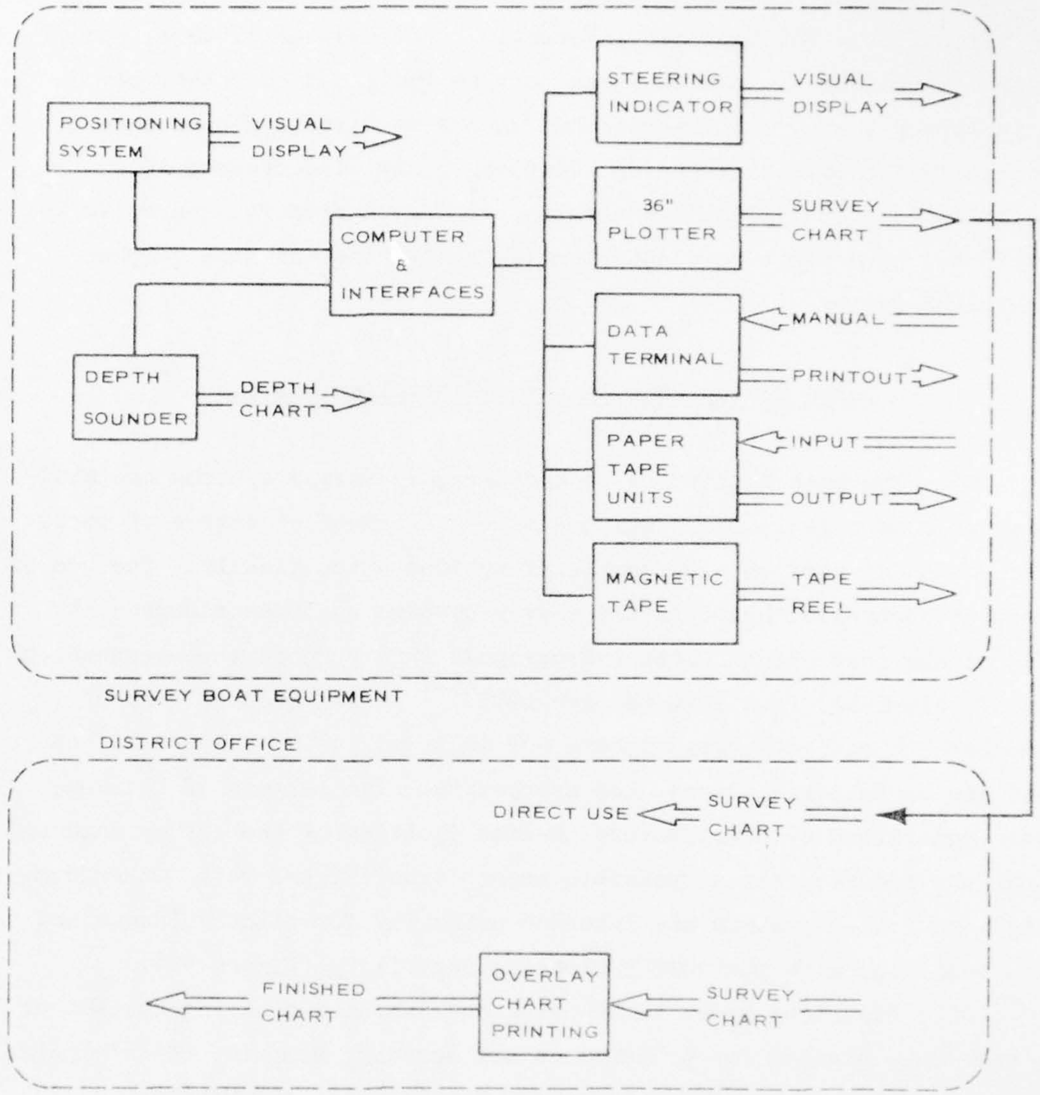

Figure 94. Minicomputer-controlled survey system for on-line chart plotting

fitted their operational needs. However, the computer-controlled system is not limited to one type of positioning equipment. It can be interfaced with whichever positioning system best meets the needs of a specific District.

208. To add to the experience of Norfolk, the Memphis District adapted this system to inland waterway use. Software was modified to

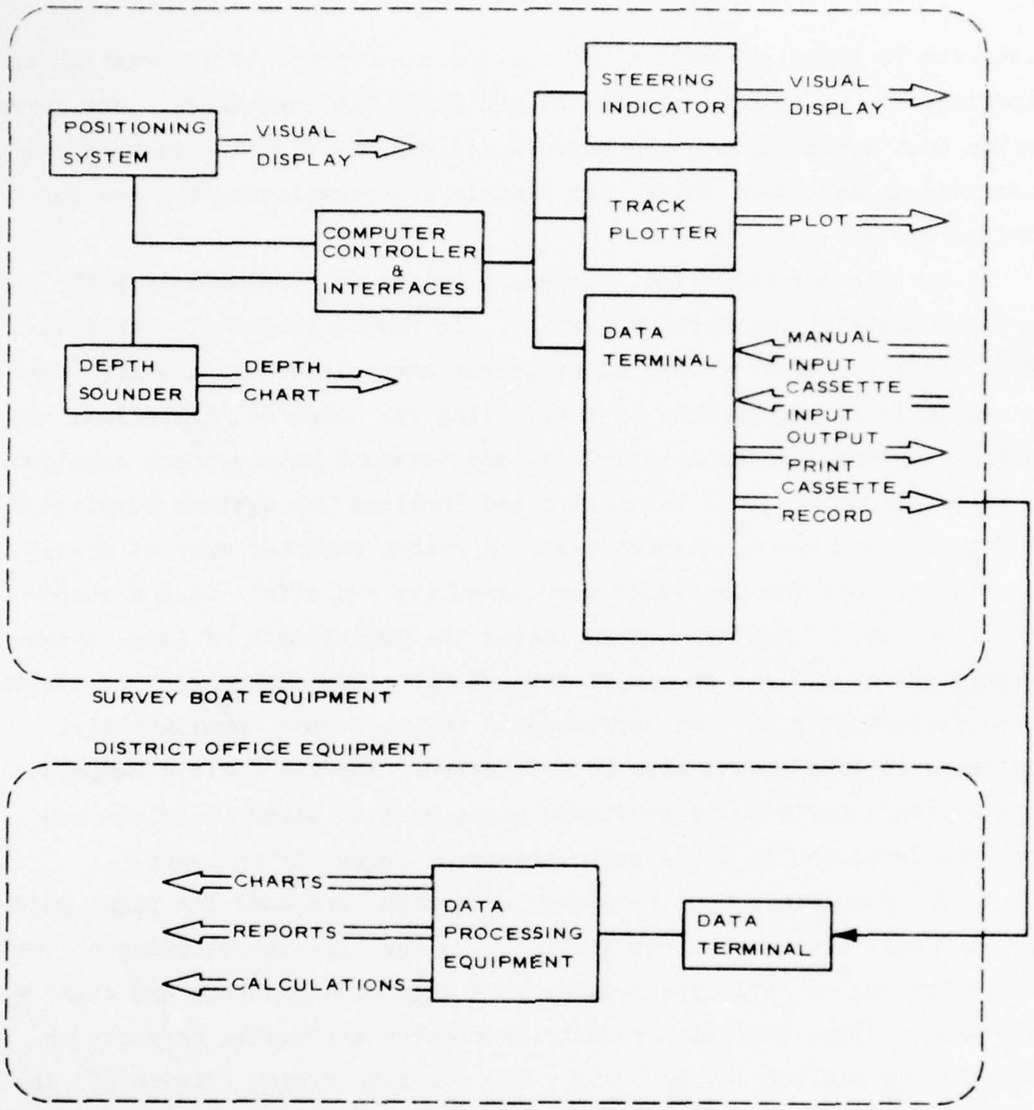

Figure 95. Minicomputer-controlled survey system for off-line chart plotting

meet river survey needs where these differed from coastal survey needs. For instance, river surveys require slope and stage adjustments rather than tidal adjustments. Memphis and Norfolk now have fully integrated hydrographic survey systems that enable District personnel to accomplish far more than was possible prior to this automation effort. Personnel from both Districts have been extremely helpful in assisting other

Districts in their automation efforts and are sources of information and experience on which other Districts can rely with confidence. For large survey boat applications, the Norfolk and Memphis District systems are commended as excellent guides for Districts contemplating systems for similar needs.

209. The Norfolk/Memphis approach relies on a relatively high level of District personnel expertise. To reduce personnel technical level needs and effort, several Districts have elected to acquire large hydrographic survey systems by contracting for complete, installed, and working systems. As examples, Tulsa and Savannah have systems supplied by Teledyne/Geotech, and Wilmington and Portland use systems supplied by Motorola and Decca, respectively. A system supplier must of necessity charge more for the added responsibility and effort than a component supplier. Districts contemplating the procurement of large hydrographic survey systems should compare the total estimated cost of system installation using the two approaches. Software cost, availability, and compatibility should also be considered. For the Norfolk/Memphis-type systems, software is available at no cost to other Districts and has been developed to fit a wide variety of Corps survey needs.

210. Some minicomputer-controlled systems are used for pilot guidance and data acquisition but are intended for off-line plotting of the data. Systems of this type require less expensive plotters and thus cost less. Since they also require less space and power, they can be installed on smaller survey boats. The off-line system (Figure 95) depicts the recording of the data on a cassette, but paper tape or reel-type magnetic tape units could optionally be used. If cassette recording is selected, any of the data transmission methods illustrated in previous discussions on microcomputers or data loggers may be used. The primary advantage of this type of system, compared with a microcomputer survey system, is the greater versatility and capability of the software.

Microprocessor-Controlled Survey Systems

211. An intermediate level of automation is available in the use

of microcomputer and desk-calculator-controlled survey systems. Systems in this class can provide pilot guidance and data recording (Figure 96). Data plotting is performed in the District office from field data records, usually in the form of magnetic tape. Complete survey systems in this class are available from Decca and Motorola. Morgan Data Systems will supply several different models of a microcomputer survey system excluding the positioning system.

212. Microcomputer-controlled survey systems offer the user considerable savings in cost, size, and weight compared with minicomputer survey systems. They can be installed on smaller survey boats and will give pilot guidance and data-recording capability to adequately meet many of the Corps application needs. Microcomputer systems from Morgan Data Systems can be readily interfaced with any of the electronic positioning systems from the major suppliers if the electrical output format of the DME is appropriately specified when it is procured.

213. Data plotting for microcomputer-controlled survey systems is in an off-line mode. Various means can be employed for transmitting the data to the District office for processing and for getting the plots back to the end user. Figure 96 illustrates the use of telephone line data transmission as one option and direct transport of the cassettes as another. Telephone line data transmission could also transmit processed data back to a field office plotter for one-day chart availablity if project needs warrant the extra cost.

214. Microcomputer systems are small enough to be used on trailerable boats and offer a good compromise in system performance in those applications where pilot guidance is needed, but waterway size and travel requirements restrict the selection to small boats.

215. MonArk Boat Co. manufactures a 23-ft small survey boat that is trailerable but still large enough to carry the equipment complement illustrated in Figure 97. All of the components listed are relatively low-power units suitable for battery operation. Figure 98 also presents another aspect of field operations only now starting to be explored--field plotting of survey data off-line. By setting up data handling machines at the field site, survey plots can be generated the same day

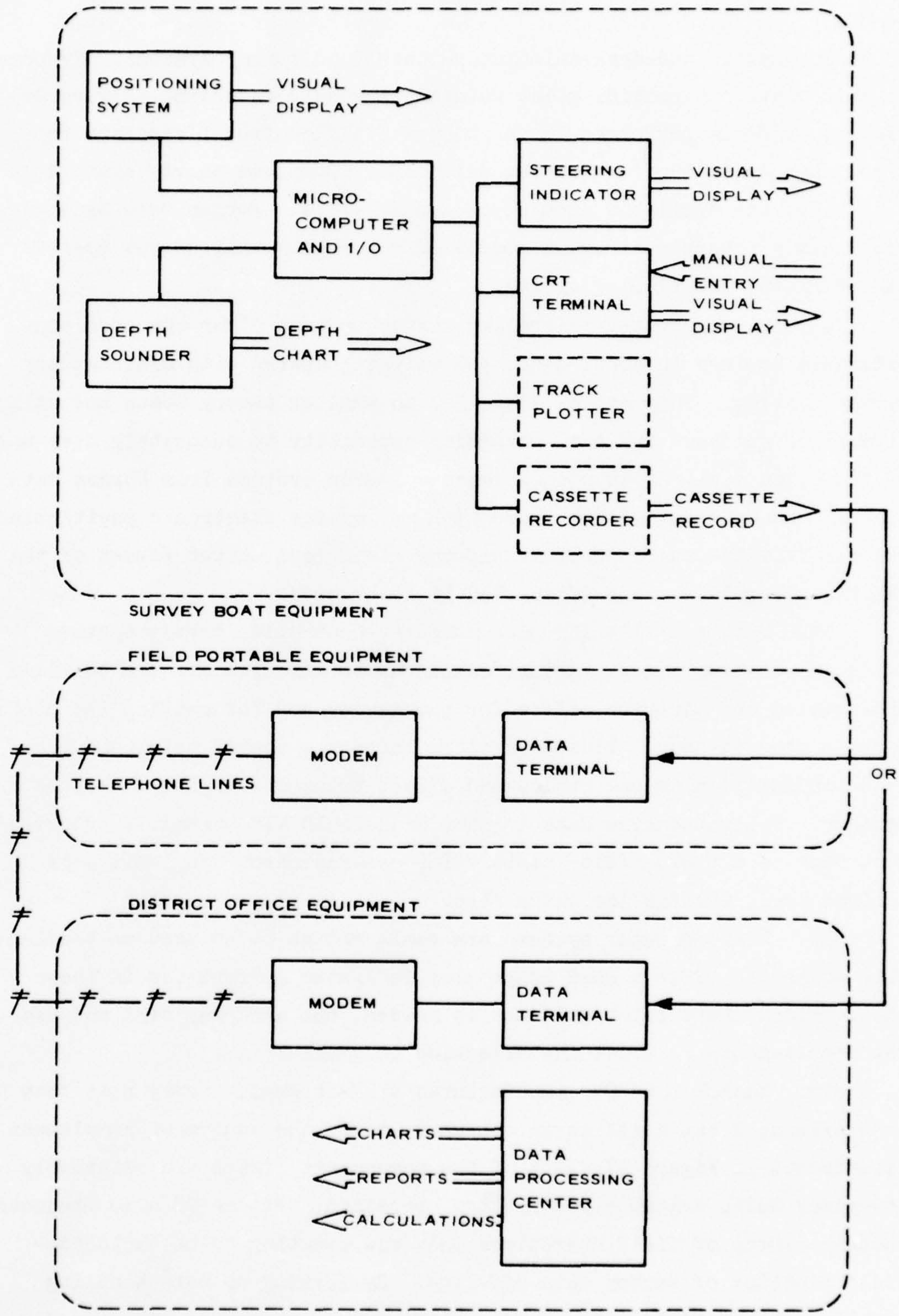

Figure 96. Microprocessor-controlled survey system for on-line pilot guidance and off-line chart plotting

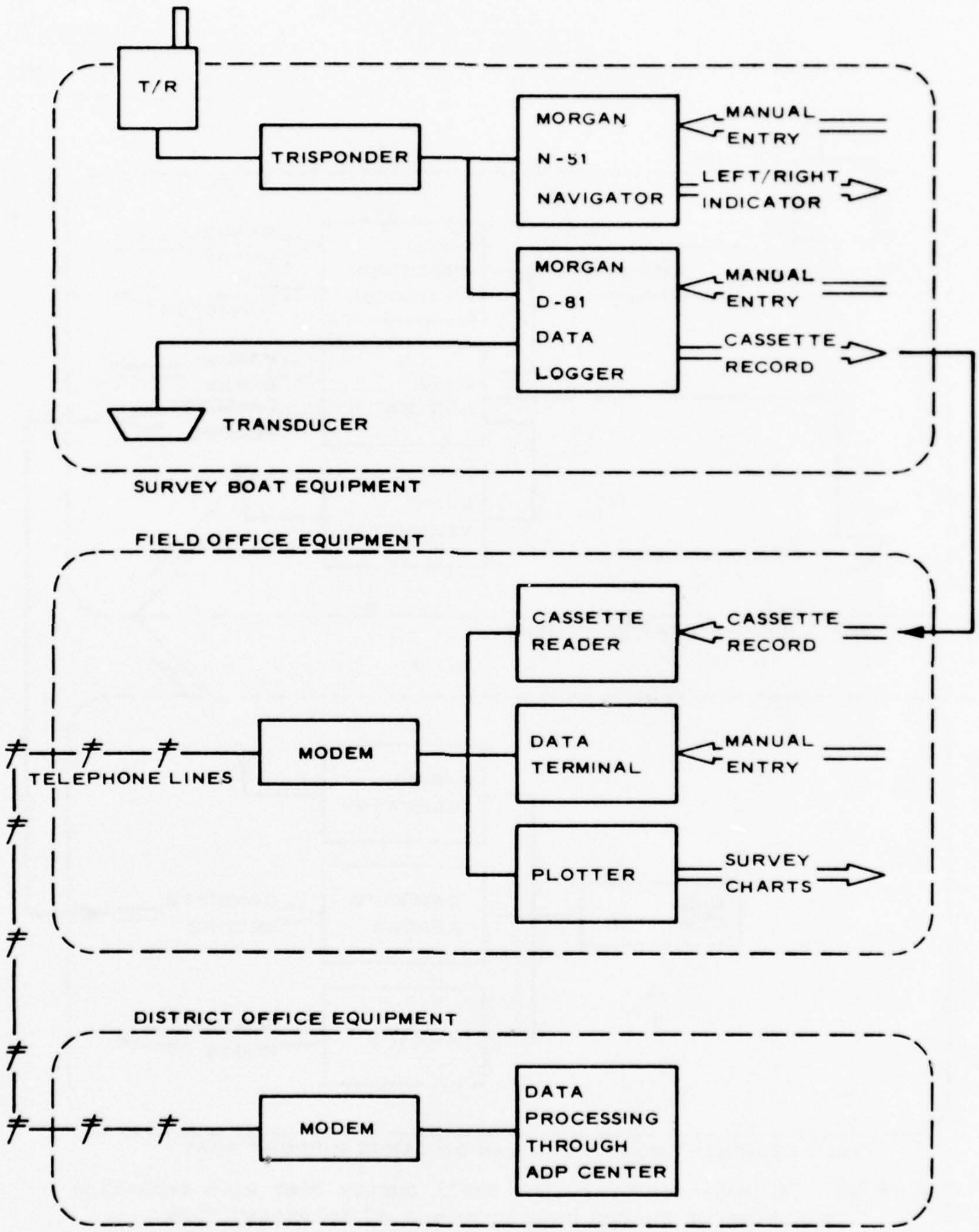

Figure 97. Microprocessor-guided small survey boat with survey plots available at field office site

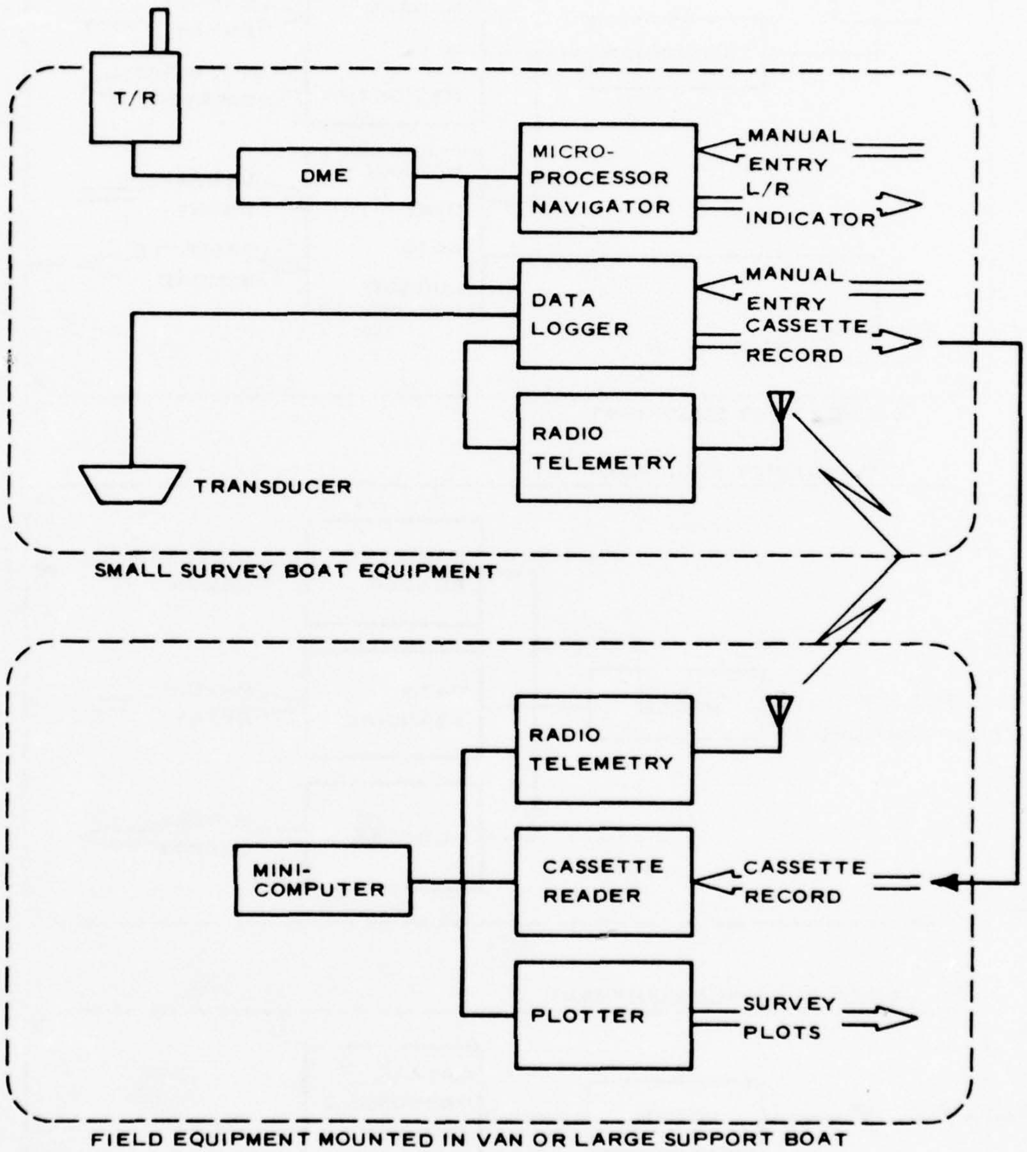

Figure 98. Microprocessor-guided small survey boat with real-time plotting of survey data by means of telemetry link

the survey is made. Telephone communication with the District ADP Center is used to extend the data-processing capability to the field site. The Mobile District is already using telephone communication to the District office for data entry and same-day plotting. Field plotting of the processed data as illustrated in Figure 97 is contemplated.

216. Field site data processing can be extended a step further if real-time survey plots are needed, but the waterway restricts boats to a trailerable size. Figure 98 illustrates a small-boat survey system with a radio telemetry link to a mobile field office in a van or large support boat. Survey plots using this system could be made on-line as they are in large survey boats. The cassette record provides a short-delay backup in case of telemetry problems.

217. This approach has been used for some coastal surveys at Fort Belvoir. Decca and Teledyne/Geotech have expressed willingness to supply a complete system in this configuration.

Small-Boat Data Logger Systems

218. The simplest level of survey system automation involves automatic data recording of depth and position. This class system is generally referred to as a data logger system. Several Districts have data loggers to record data on computer compatible magnetic tape, which decreases data-processing time compared with cassette recording. Use of this type of data-logging system by the San Francisco District is reported in the 1973 conference proceedings.[5] The magnetic tape units generating computer compatible tape are larger, heavier, and more power-consuming than cassette recorders. This type of data logger is thus restricted to use on large survey boats (Figure 99).

219. Data loggers developed for small boats are small, lightweight, low in power consumption, and relatively low in cost. The experience of the Buffalo District with a system of this type is reported in the 1975 conference proceedings.[7] Operations that require trailering a survey boat to a number of sites will probably find this type of system an optimum solution. Small-boat data loggers can be electrically

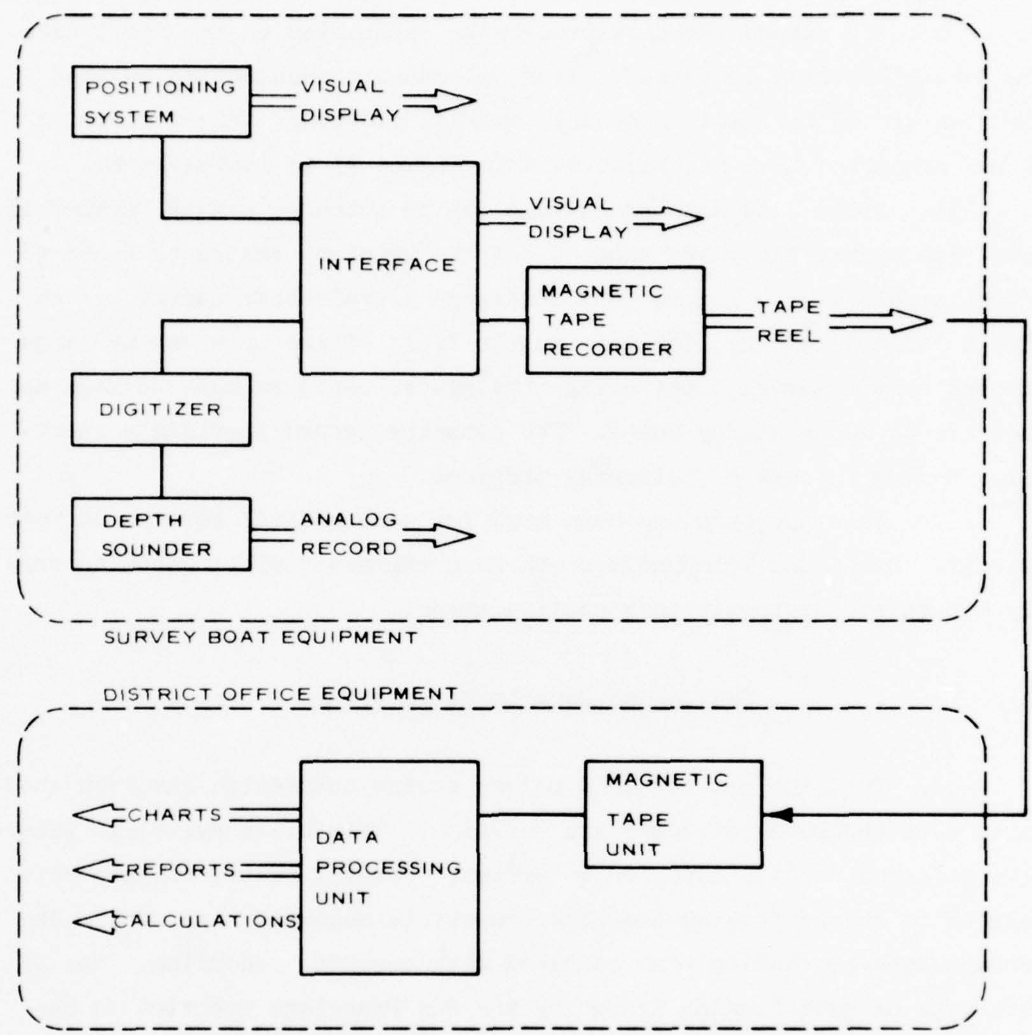

Figure 99. Large-boat data logger survey system

interfaced with any of the electronic positioning systems. However, size, weight, and power limitations of small boats will usually deter the use of nonline-of-sight positioning systems. Thus, it is expected that most small-boat data loggers will be integrated with small, lightweight DME to form a compatible survey system.

220. Figure 100 shows a small-boat data logger survey system with a separate depth sounder interfaced to the data logger. The depth sounder, such as a Raytheon DE 719, provides a conventional depth chart

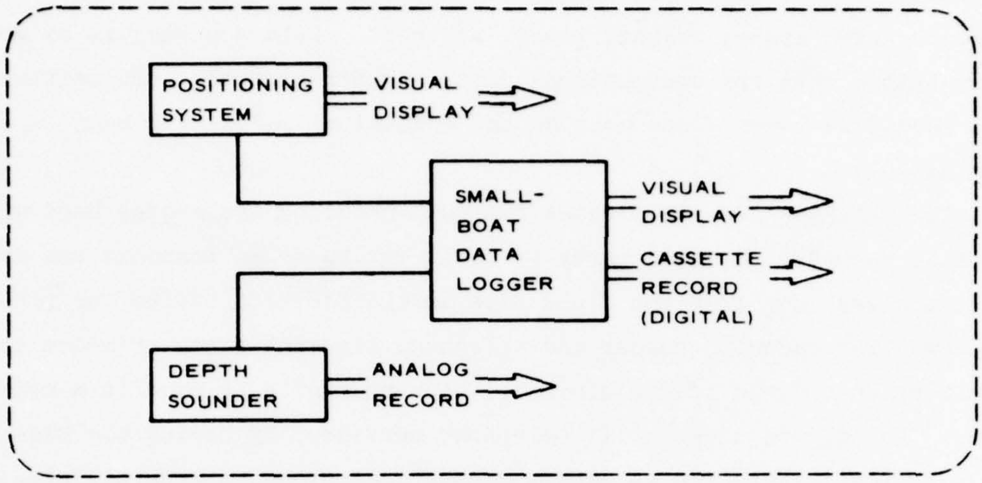

Figure 100. Small-boat data logger with separate depth sounder

for the boat operator to view during field operations. It also acts as a back-up record in the event that the cassette record is faulty.

221. Figure 101 depicts a small-boat logger with the depth measurement circuits built in as an integral part of the data logger; a separate depth sounder is not required. An on-line display of depth is

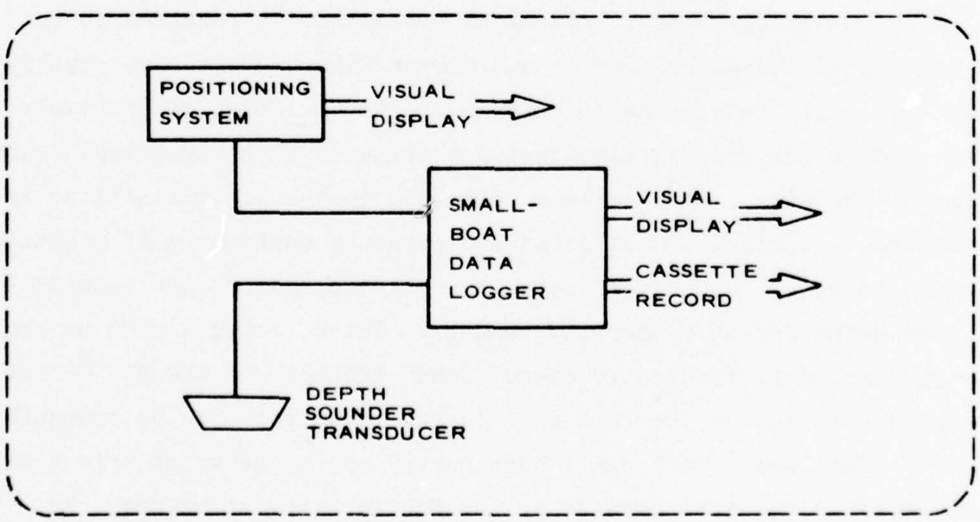

Figure 101. Small-boat data logger with integral depth measurement circuits

provided but no chart; only a cassette record is made of the data. This approach saves space, weight, power, and cost. Data accuracy is as good as or better than the conventional depth sounder approach, and maintenance should be lower since most of the mechanical parts have been eliminated.

222. Figure 102 illustrates two data-handling techniques used with cassette records. A field party suitably equipped can transmit the data collected each day from the field site to the District office for processing. The cassette reader and telephone line interface or modem can be set up in a field office close to the survey site or even in a motel room. The only requirement is telephone service. By having the District office initate the telephone connection through a Federal Telecommunications System (FTS) operator, the long-distance toll charges can be greatly reduced. A telephone modem is also needed at the District office to couple the telephone lines to the computer equipment.

223. An alternate procedure, also illustrated in Figure 102, is to mail or hand-carry the cassette records to the District office where the cassette record can be changed to a computer compatible magnetic tape reel. Most District ADP Centers have magnetic tape units for high-speed data entry. A special cassette-to-reel translator is required to use this procedure. Teledyne/Geotech and Morgan Data Systems have supplied cassette-to-reel translators to Buffalo and New Orleans, respectively. This procedure has several disadvantages compared with electrical transmission of the data. Sending data cassettes to the District office is slower than electrical transmission and probably costs more if a special trip must be made. Second, cassette-to-reel translators are considerably more expensive than cassette readers. Third, records made on small reel-type recorders frequently cause "read" problems on the ADP Center tape units even though the tape reel format is supposed to be compatible.

224. The lowest cost small-boat survey system known at this time is one recently put into service by the Mobile District office. As shown in Figure 103, this system uses a single-range DMU. The boat operator is guided on the desired course by the shore station operator through the voice channel of the CA-1000D. This small-boat survey

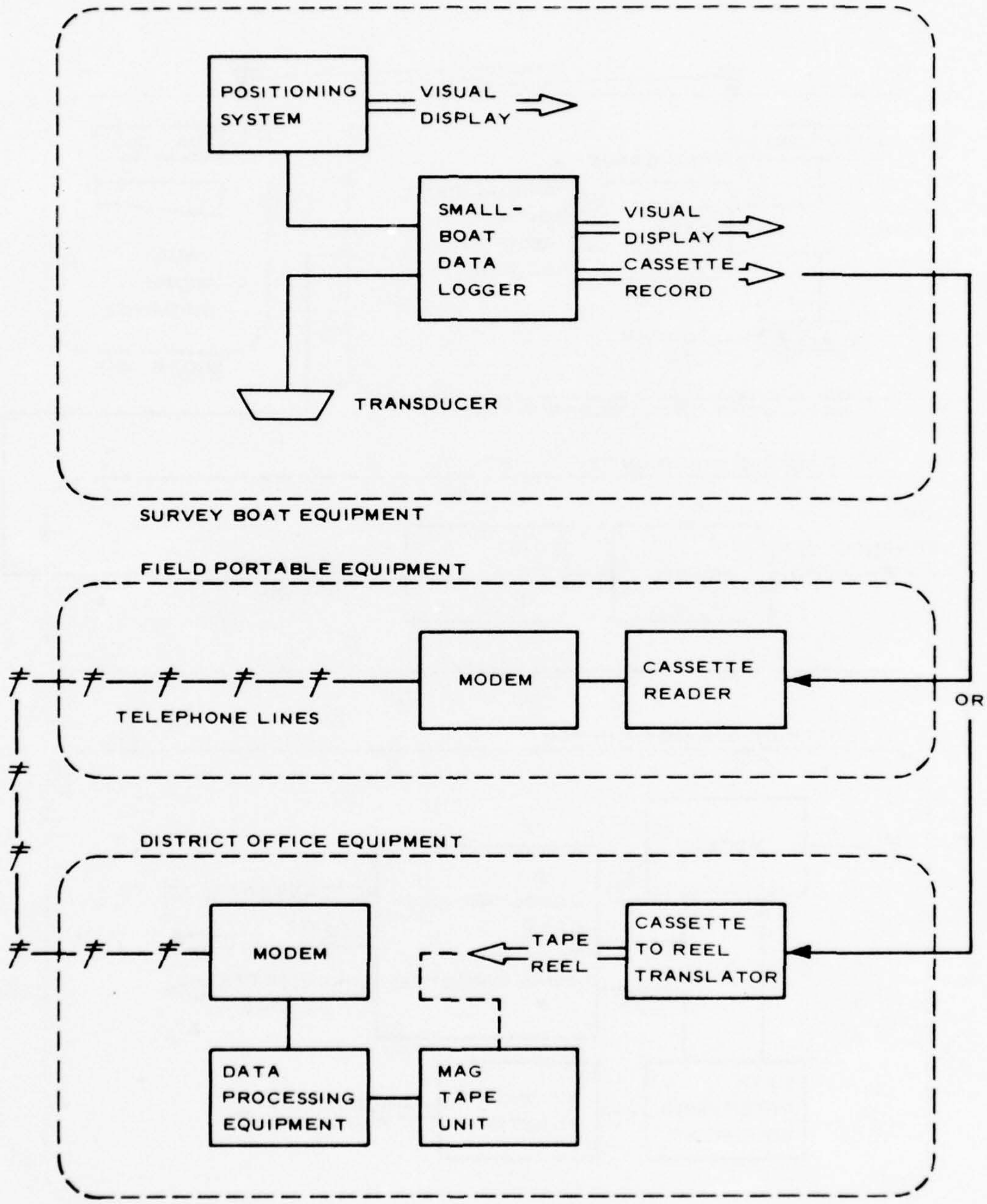

Figure 102. Small-boat data logger with optional data exchange capability

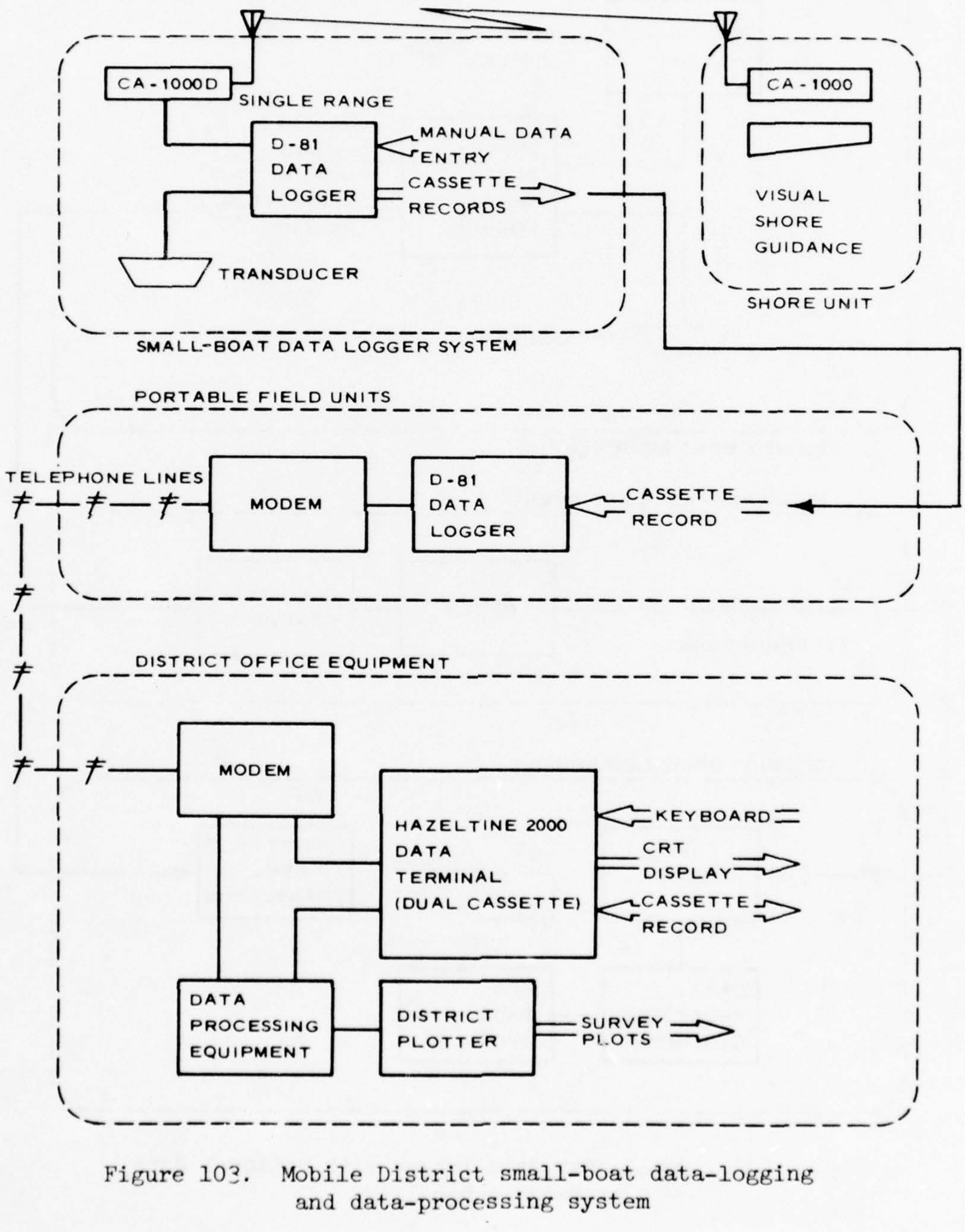

Figure 103. Mobile District small-boat data-logging and data-processing system

system is an electronic equivalent of a mechanical tag-line system but with a number of advantages: (a) the data are in machine readable form; (b) the boat can move much faster; (c) the DME beam is not a hazard to boat traffic as is a steel wire; and (d) the range length can be considerably longer than a wire line. The D-81 data logger includes a depth measurement function plus the recording and data entry functions. Thus, a separate depth sounder is not necessary. The data logger is a low-power consumption unit so that a small aircraft battery can normally suffice for a full day's survey work.

225. The D-81 data logger also has the capability of acting as a cassette reader. The Mobile District is using the D-81 to transmit data to the District ADP Center at the end of each day's field operations. A simple commercially available modem is used to couple the D-81 to the telephone line. The field party has the District office contact them on an FTS line to reduce long-distance toll charges.

226. Data received in the ADP Center can be transmitted directly to a host computer or can be recorded on the Hazeltine 2000 cassette unit for editing and subsequent processing. Programs have been developed by the Mobile ADP Center to handle most routine editing by means of the computer so that data is plotted within minutes after data transmission. For nonroutine editing, the Hazeltine 2000 CRT terminal display and keyboard provide a convenient operator station. Following the editing operation, the Hazeltine data terminal is used to transmit the data to the host computer for processing. Plotting of the data on the District plotter follows in short order.

227. Mobile personnel are contemplating even more sophisticated improvements, such as locating a plotter at the field site. Survey plots will then be available on a same-day basis to the field crews and plot users.

PART VIII: PROCUREMENT, ACKNOWLEDGMENTS, AND CONCLUSIONS

Procurement

228. Procurement of hydrographic survey equipment can pose problems as difficult and complex as the technical decisions. Since much of the equipment is in a price range above $10K, Government regulations require contract procurement unless the equipment is on a General Services Administration (GSA) schedule. Another factor to be considered is the impact of Army Regulation (AR) 18-1 that governs the procurement of computers and peripherals. Computer procurement regulations have grown progressively more restrictive in recent years and should be investigated at an early stage in the planning. A third factor is the systems approach selected by District personnel. One approach is for Districts to procure individual components of a system and use Government personnel to interface, assemble, and check out the system. An alternate approach is to procure a complete system that the contractor will install and check out on the Government boat specified. Both approaches have been used successfully by several Districts. The decision in individual cases will depend on the qualifications of Government personnel available and the willingness of management to commit key personnel to the survey program during the learning phase. Complete system procurement involves a higher capital investment but smaller Government labor costs than the component procurement approach. Approximate price lists of positioning and hydrographic survey systems are included as Figures 104 and 105, respectively.

229. An aid to procurement exists in the GSA contract schedule. Equipment on a current GSA contract schedule can be procured with much less trouble than is necessary for regular contract procurement. The GSA contract schedule eliminates the need to write specifications and to advertise for bids or proposals. Considerable savings in time and money can thus be saved by using this procurement procedure. Prerequisites to using the GSA procurement procedure are: (a) the equipment needed can be found on a GSA contract, and (b) the GSA contract is in

Approximate Price Range	System	
> $100K	Argo	2-range
	OMI	2-range
	Artemis	1-range, 1-azimuth
	PLANS	Multirange
	Autotape	3-range
$70K → $85K	Autotape DM40A	Basic two-range
	Hydrotrac	Basic 2-range
	Hi-Fix-6	Basic
$50K → $70K	Raydist	Basic T-system
	Tellurometer	MRB 201 Basic 2-range
	Trisponder	Multichannel DMU, 6-range
	Hi-Fix	Basic 2-range
	Raydist	Basic 2-range
	Hydrobar	Basic range-azimuth
$35K → $50K	Syledis	3-range
	Maxiran	3-range
	Syledis	2-range
$25K → $35K	Maxiran	2-range
	Mini-Ranger	2-range with space diversity antenna
	Mini-Ranger	3-range
	Trisponder	Multichannel DMU, 3-range
$20K → $25K	Mini-Ranger III	Basic 2-range
	Trisponder 220	Basic 2-range
	Trisponder 260	Basic 2-range
	Miniran	Basic 2-range
< $10K	Tellurometer	CA-1000D

Figure 104. Approximate prices of positioning systems

Positioning System	Computer/Microcomputer System	Depth System	Translator/ Record Interface	Total
2-Range Autotape $85K	Norfolk/Memphis (PDP-8) On-Line Plotting (36 in.) $40K	Ross $15K		$140K
2-Range Raydist $55K	Norfolk/Memphis (PDP-8) On-Line Plotting (36 in.) $40K	Ross $15K		$100K
2-Range Trisponder $25K	Norfolk/Memphis (PDP-8) On-Line Plotting (36 in.) $40K	Raytheon 719 I. T. 110 $ 5K		$ 70K
2-Range Raydist $55K	Teledyne/Geotech $40K	Raytheon $ 5K		$100K
2-Range Trisponder $25K	Decca/Autocarta $40K	Raytheon $ 5K		$ 70K
2-Range Mini-Ranger $25K	Mini-Ranger Data Processor $25K	$ 5K	Translator $10K	$ 65K
2-Range Trisponder $25K	Morgan N51 Automatic Positioning System $15K	Morgan D-81 $12K	1 Modom $ 1K	$ 53K
2-Range Mini-Ranger $25K		Teledyne $15K	Translator $18K	$ 58K
2-Range Trisponder $25K		Morgan D-81 $12K		$ 37K
1-Range Tellurometer CA-1000D $8.5K		Morgan D-81 $12K		$ 21K

Figure 105. Approximate prices of complete hydrographic survey systems

force at the time the procurement is initiated. The second item is noted because GSA contracts are for limited time intervals and are not always renewed.

230. Companies known to have equipment on GSA schedules at the present time are listed below:

a. Cubic - Positioning equipment (Autotape)

b. Decca - Autocarta Survey Systems (includes Trisponder positioning equipment)

c. Motorola - Positioning equipment (Mini-Ranger)

d. Raytheon - Depth-measuring equipment

Acknowledgments

231. Information regarding the equipment described herein has been secured from sales publications and telephone conversations with the respective manufacturers. It has been possible to include only a brief summary of the vast volume of literature available to the prospective user. Readers are encouraged to contact the manufacturers (Appendix A) directly for literature on components and systems that appear to be of potential use to them. Because only a limited number of models have been described, and as new models are being added continuously, inquiries to the manufacturers should be phrased to obtain a complete and up-to-date description of products available. It is hoped that this report will be a useful starting point for readers interested in hydrographic surveying, but in a field changing so rapidly, that is all it can be.

Conclusions

232. The techniques and methods presented in this study cover the range from old-fashioned to those that are still in the development or theoretical stage. Where existing and well-developed techniques can adequately meet application needs of the readers, they will generally prove to be the most economical to apply. Where existing techniques are inadequate, the undeveloped techniques suggested should stimulate ideas

that will lead to adequate and efficient operations. The Corps operations have come a long way during the past few years in applying a rapidly developing technology to hydrographic surveying. With good communications between survey groups in different Districts, a continuing exchange of ideas and experiences can be expected that will advance the state of the art and promote a future even more productive and rewarding to those in the field. Appendix C tabulates equipment type by District, and Appendix D names survey personnel in each District who can aid in promoting the above information interchange.

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2. Downing, G. C., "Supplement No. 1 to the Hydrographic Survey Conference, 30-31 May 1973," Aug 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Westervelt, G. J., "Pulse Doppler Sonar Navigation System Concepts and Implementation," IEEE 1976, Position Location and Navigation Symposium, IEEE Publication 76CH1138-7 AES, 1976, p 53.

4. Hart, E. D. and Downing, G. C., eds., "Hydrographic Survey Conference, 9-11 May 1972," Oct 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

5. ________, "Hydrographic Survey Conference, 30-31 May 1973," Oct 1973, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

6. ________, "Third Hydrographic Survey Conference, 21-22 May 1974," Dec 1974, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

7. ________, "Fourth Hydrographic Survey Conference, 5-6 November 1975," Mar 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

APPENDIX A: LIST OF MANUFACTURERS OF HYDROGRAPHIC SURVEY EQUIPMENT POTENTIALLY USEFUL FOR INLAND WATERWAYS

Actron Industries, Inc. 700 Royal Oaks Drive Monrovia, CA 91016	Dr. Duan W. Linker 213/359-8216
Alpine Geophysical Associates Inc. 70 Oak Street Norwood, NJ 07648	
Ametek/Straza 790 Greenfield Drive El Cajon, CA 92021	Mr. J. B. Cowan 714/442-3451
Bernsten Cast Products Box 3025 Madison, WI 53704	
Bludworth Marine Division States Electronics Corporation 10 Adams Street Linden, NJ 07036	Mr. W. C. Blaisdell 201/925-8650
Breaux's Bay Craft, Inc. P. O. Box 306 Loreauville, LA 70552	Mr. Roy Breaux 318/229-4246
Crenco, Inc. 720 St. Asaph Street N Alexandria, VA 22314	703/548-2544
C-Tech Ltd. Montreal Road Cornwall, Ontario	613/933-7970
Cubic Industrial Corp. 4285 Ponderosa Ave. San Diego, CA 92123	Mr. C. B. Hempel 714/279-7400
Decca Survey Systems, Inc. P. O. Box 22397 Houston, TX 77027	Mr. Earl Smith 713/783-8220
Del-Norte Technology, Inc. P. O. Box 696 Euless, TX 76039	Mr. Jim Stegall 817/267-3541
Digicourse, Inc. P. O. Box 50699 New Orleans, LA 70150	504/733-6000

Edo Western Corp. 2645 S 2nd W Salt Lake City, UT 84115	Mr. Rad Ferre 801/486-7481
EG&G International Environmental Equipment Division 151 Bear Hill Road Waltham, MA 02154	Represented by Harvey Lynch, Inc. Houston, TX 77036 ATTN: Mr. Costango
Environmental Devices Corp. Instrument Division, Tower Bldg. Marion, MA 02738	Mr. Frank DeLuca 617/748-0366
General Instrument Corp. 33 Southwest Park Westwood, MA 02090	Mr. Gill Mackin 617/326-7815
Geophysical Survey Systems, Inc. 16 Republic Road N. Billerica, MA 01862	Mr. G. R. Tostengard 617/667-4341
GTE Sylvania, Inc. P. O. Box 188 Mountain View, CA 94040	Mr. J. W. Patterson 415/966-6137
Hewlett Packard 1820 Embarcadero Road Palo Alto, CA 94304	Regional Sales Offices Throughout U. S. A.
Hydrocarta Corp. 9730 Town Park Drive Houston, TX 77036	Mr. Collins Weeks 713/771-1263
Ikonix 13708 Smallwood Court Chantilly, VA 22021	R. L. Stites 703/968-7484
Innerspace Technology, Inc. 27 Frederick Street Waldwick, NJ 07463	201/447-0398
International Imaging Systems 510 Logue Avenue Mountain View, CA 94040	Mr. Don Ross 415/968-6137
InterOcean Systems, Inc. 3510 Kurtz Street San Diego, CA 92110	Mr. Jim Lasch 714/299-4500
Kemp Instruments, Inc. 4306 Governors Drive W, Suite N Huntsville, AL 35805	Mr. Jim Hale

Klein Associates, Inc. Route 111, RFD 2 Salem, NH 03079	Mr. Martin Klein Mr. Gene Schartz 603/893-6131
Magnavox 2829 Maricopia Street Torrance, CA 90503	Mr. Ed Hecht 213/328-0770
Martek Instruments, Inc. 879 W 16th Street New Port Beach, CA 92660	714/645-1170
MonArk Boat Co. P. O. Box 210 Monticello, AR 71655	501/367-5361
Morgan Consulting, Inc. 357 N. Eglin Parkway Fort Walton Beach, FL 32548	Mr. John Morgan 904/242-1413 Mr. Larry Anderson
Motorola, Inc. Government Electronics Division 8201 E. McDowell Road Scottsdale, AZ 85252	Mr. R. C. Olsen Mr. Tom Gilb 602/949-3181
NanoFast West Erie Street Chicago, ILL 60610	
Navigation Management, Inc. P. O. Box 158 Anthony, FL 32617	Mr. J. W. Lassiter 904/732-0904
Ocean Applied Research Corp. 10447 Roselle Street San Diego, CA 92121	714/453-4013
Ocean Research (ORE) Falmouth, MA 02541	617/548-5800
Odom Offshore Surveys, Inc.	Mr. Harold Odom 504/766-6330 P. O. Box 927 Baton Rouge, LA 70821
Paragon Electronics Corp. 14810 NE 146th Place Woodinville, WA 98072	206/485-1960

Plessey Environmental Systems P. O. Box 80845 San Diego, CA 92138	 714/278-6500
Raytheon Corp. P. O. Box 360 Portsmouth, RI 02871	Mr. C. Daniels Mr. David Rattray 401/874-8000
Ross Laboratories, Inc. 3138 Fairview Ave. E Seattle, WA 98102	Mr. Wayne Ross Mr. John Dudley 206/324-3950
Sanders Associates, Inc. 95 Canal Street Nashua, NH 03060	Mr. Richard Northrup 603/885-4894
Sercel, Inc. Suite D10 4800 W 34th Street Houston, TX 77018	Mr. John L. DeVault 713/688-9433
Software Consultant 617/484-0736	Mr. J. C. Kilbane 61 Chester Road Belmont, MA 02178
Spectral Data Corp. 120 W John Street, Hicksville Long Island, NY 11802	 516/433-3910
Sperry Rand Corp. Route 29 N Charlottesville, VA 22901	Mr. C. R. Kenney 703/973-3371
Teledyne/Geotech 314 Montgomery Street Alexandria, VA 22314	Mr. Bill Whyte 703/836-3882
Teledyne/Raydist P. O. Box 1275 Hampton, VA 23361	Mr. J. W. Newsome 703/723-6531
Tellurometer Division Plessey Electronics Corp. 89 Marcus Blvd. Hauppauge, NY 11787	Mr. Charles G. Romaniello 516/231-7710
Tracor, Inc. 6500 Tracor Lane Austin, TX 78721	 512/926-2800

APPENDIX B: EQUIPMENT CROSS INDEX

LINE-OF-SIGHT POSITIONING SYSTEMS

ACCI

Alpine Geophysical

Crenco

Cubic

Del Norte

Motorola

NanoFast

Navigation Management

Tellurometer

NONLINE-OF-SIGHT POSITIONING SYSTEMS

Cubic

Decca

Hydrocarta

Odom

OMI

Sercel

Teledyne/Raydist

Tracor

ACOUSTIC NAVIGATORS

Ametek/Straza

Edo Western

General Instrument

Magnavox

ORE

Sperry Marine

Raytheon

COMPUTER-CONTROLLED HYDROGRAPHIC SURVEY SYSTEMS

Cubic

Decca

Digital Equipment Corporation

Hydrocarta

Motorola

Teledyne/Geotech

MICROPROCESSOR-CONTROLLED SURVEY SYSTEMS

Decca

Morgan Consulting

Motorola

DATA-LOGGING SYSTEMS

Cubic

Morgan Consulting

Ross

Teledyne/Geotech

SATELLITE POSITIONING SYSTEM

Magnavox

DEPTH MEASUREMENT

Bludworth

Edo Western

Innerspace Technology

InterOcean

Raytheon

Ross

SUBBOTTOM PROFILERS

Del Norte

Edo Western

EG&G

Klein

ORE

SIDE SCAN SONAR

Edo Western

EG&G

Gould

Klein

ORE

Westinghouse

MULTIBEAM DEPTH MEASUREMENT

Chesapeake Instrument Corp.

C-Tech Ltd.

General Instrument Corp.

Raytheon

Ross

MARINE COMPASSES

Digicourse

Sperry Marine

WAVE, TIDE, RIVER STAGE GAGES

InterOcean/Bass

Ocean Applied Research

RIVER DISCHARGE

Westinghouse

Decca/Krupp

Accusonic/ORE

OPTICAL TRACKERS

GTE Sylvania

Sanders Associates

ENVIRONMENTAL MEASUREMENTS

Plessey Environmental Systems

Hydro Products

Environmental Devices Corporation

General Oceanics, Inc.

InterOcean

HydroLab

OPTICAL REMOTE SENSING

Actron Industries

International Imaging

Spectral Data Corp.

LAND SURVEY SUPPLIES

Bernsten Cast Products

Hewlett Packard

Tellurometer

Cubic

SURVEY BOATS

Breaux's Bay Craft

MonArk Boat Co.

PROGRAMMING CONSULTANTS

Kilbane

Ikonix, Inc.

APPENDIX C: CORPS OF ENGINEERS HYDROGRAPHIC SURVEY INVENTORY, OCTOBER 1975

Division/ District	Positioning System	Mini-Computer Processor	Micro-Computer Processor	Hardware Data Processor	Depth Measurement Equipment	Data Plotter	Mag Tape Reel	Mag Tape Cassette	Paper Tape	Comments
New England Division	Autotape		Teledyne		Raytheon			Teledyne		
New York	Autotape			Ross	Ross		Ross			
	Autotape				Bludworth					
Baltimore	Raydist	PDP-8			Ross	Houston 30"			Teletype	
	Hi-Fix				Bludworth					
Norfolk	Raydist (2)	PDP-8 (2)			Ross (2)	Houston 30" (2)			Teletype (2)	
Philadelphia	Autotape (2)	PDP-8			Ross, Raytheon		DEC			
	Autotape	PDP-10			Bludworth (11)	H.P.				Dredge
Wilmington	RPS	Interdata			Raytheon	Houston 10"		Mobark		
Mobile					Ray (5) Blud (5)					
Savannah	Raydist	PDP-8			Ross, Blud (4)	Complot			Teletype	
Charleston	Raydist	PDP-8			Raytheon	Houston 30"			Teletype	
	Raydist				Raytheon					
Jacksonville	RPS	Interdata			Raytheon (2)					Dredge
	Mini-Ranger III				Raytheon			Motorola		
Alaska	Autotape				Raytheon (4)					
Portland	Trisponder	PDP-11			Atlas	Houston			DEC/HSPT	
	Trisponder (3)				Ross (4) Ray (4)					
Seattle	Mini-Ranger II				Ross (2) Ray (4)					
Walla Walla					Ray (2) Ray (ChSweep)					
Los Angeles	Trisponder		H.P. Calc		Ross			DataMatic 4000		
Sacramento					Bludworth (2)					
San Francisco	Autotape			Ross 565	Ross, Ray (2)		Ross			
Buffalo	Mini-Ranger III		Teledyne		Ray (2) Blud			Teledyne		
Chicago	Autotape				Ray (2) Blud (3)		Cubic			
Detroit	Hi-Fix				Blud (13) Atlas (1)					
					Ray (1) Edo (1)		Kennedy			
Rock Island	Trisponder		Wang Calc		Ross, Ray (2)			Wang		
St. Paul	Autotape				Raytheon (5)			Cubic		

(Continued)

Division/ District	Positioning System	Mini-Computer Processor	Micro-Computer Processor	Hardware Data Processor	Depth Measurement Equipment	Data Plotter	Mag Tape Reel	Mag Tape Cassette	Paper Tape	Comments
St. Louis	Autotape				Ray (4) Ross (2)				Cubic	
Memphis	Raydist Mini-Ranger III (2)	PDP-8			Ross, Ray (11) Raytheon	Calcomp		Motorola		
Vicksburg	Hydrodist (6)*				Ray (21) Blud (18)					
New Orleans	Autotape			Cubic	Ray (37) Ross (5) Blud (2)		Cubic			
Galveston					Raytheon (9)					
Little Rock	Mini-Ranger III	Interdata			Ray (4) Blud (7)	Houston		Motorola		
Albuquerque										
Ft. Worth					Bludworth (1)					
Tulsa	Raydist	PDP-8			Ray (4) Blud (2)	Houston	Sykes			
Pittsburgh				Morgan	Morgan, Blud (2)			Morgan		
Huntington	Trisponder**	PDP-8			Ross, Ray (4)		DEC			
Louisville										
Nashville	Trisponder				Raytheon (2)					
Omaha	Hydrodist				Raytheon (4) Ross (3) Blud (4)					
Kansas City					Raytheon (8)					
WES	Trisponder (2)				Raytheon (2) Auto Sys (2)					
TOTALS	Autotape 12 Raydist 8 RPS 2 Mini-Ranger 5 Hydrodist 6* Trisponder 10 Hi-Fix 2	PDP-8 9 PDP-10 1 PDP-11 1 Interdata 3	Teledyne 2 H.F. Calc 1 Wang Calc 1	Ross 2 Cubic 1 Morgan 1	Raytheon 153 Bludworth 77 Ross 25 Atlas 2 Auto Sys 3 Ray (Sweep) 1 Morgan 1 Edo 1	Houston 8 Complot 1 Cal Comp 1 H.P. 1	Ross 2 Cubic 3 Kennedy Sykes 1 DEC 1	Teledyne 2 Mobark 1 Motorola 3 DataMatic 1 Wang 1 Cubic 1	Teletype 5 DEC 1 Cubic 1	

* Contract.

** Procurement under protest.

APPENDIX D: CORPS OF ENGINEERS HYDROGRAPHIC SURVEY CONTACTS, OCTOBER 1975

Division	District	Coordinator Name	Coordinator FTS No.
NED	Waltham, Mass.	F. Ciccone	839-7330
NAD			
	New York	W. F. Muszak	264-0181
	Baltimore	H. Epstein	922-3663
	Norfolk	R. A. Pruhs	924-3668
	Philadelphia	H. R. Spies	597-4745
SAD			
	Wilmington	A. F. Grimstead	674-9449
	Mobile	J. I. Meredith	534-2576
	Savannah	R. Harlin	287-8217
	Charleston	I. B. Kyzer	677-4366
	Jacksonville	J. C. Pruett	946-2435
NPD			
	Alaska	O. Smith	339-0150 then 907-753-2274*
	Portland	N. H. West	423-6301
	Seattle	H. Maresh	399-3413
	Walla Walla	I. S. French	442-5500
SPD			
	Los Angeles	E. M. Bratcher	798-5550
	Sacramento	H. E. Windham	448-3364
	San Francisco	W. J. Dickson	556-2404
NCD			
	Buffalo	R. Wohlart	473-0454 Ext 2287
	Chicago	J. P. Jones	353-6432
	Detroit	C. E. Lamphere	226-6816
	Rock Island	W. J. Degen	360-6268
	St. Paul	G. Kletzke	725-7544

Division	District	Coordinator Name	Coordinator FTS No.
LMVD			
	St. Louis	C. E. Meyers	279-2833
	Memphis	A. L. Wilkerson	222-3238
	Vicksburg	E. L. Howe	542-6502
	New Orleans	W. Weiser	687-1121
SWD			
	Galveston	A. Graham, Jr.	527-1366
	Little Rock	J. T. Long	740-5661
	Little Rock	T. S. Cook	740-5679
	Albuquerque	E. H. Lassen	474-2615
	Tulsa	F. Becker	736-7203
	Tulsa (Kerr Res)	C. E. Weddle	918-775-4475*
	Ft. Worth	F. B. Morrow	334-2210
ORD			
	Pittsburgh	T. E. Taylor	722-6826
	Huntington	R. R. Applegate	924-2698
	Huntington	S. K. French	924-9239
	Louisville	M. Berkman	352-5720
	Nashville	J. N. Thomasson	852-5954
	Nashville	H. M. Davis	852-5181
MRD			
	Omaha	H. E. Christian	864-4020
	Kansas City	T. Burke	758-3341
OCE		M. Millard	900-693-6984
WES		G. C. Downing	542-2747
		E. D. Hart	542-2258

* Not FTS.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Hart, Ellis Dale
Positioning techniques and equipment for U. S. Army Corps of Engineers hydrographic surveys, by E. Dale Hart [and] George C. Downing. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report H-77-10)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.
Includes bibliography.

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